GEOLOGICAL MAGAZINE

VOL. XCIV. No. 4. JULY–AUGUST, 1957

Issued 16th August, 1957

The Aberfoyle Anticline, Callander, Perthshire

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ABSTRACT

The succession in the Upper Dalradian is described. The author follows Anderson in correlating the Leny and Ben Ledi Grits. Way-up evidence indicates that the Leny Limestone does not occupy a syncline as previously supposed, but is a stratigraphical intercalation in the Leny Grits. It is shown from way-up evidence and structural analysis that the Aberfoyle Anticline closes downwards and is a synform.

INTRODUCTION

IN this paper the author reinterprets the structure of an area of Dalradian rocks near Callander (Text-fig. 1). It was formerly thought that the Dalradian rocks north of the Highland Boundary Fault there were folded into an anticline overturned towards the south-east. This fold—the Aberfoyle Anticline—was discovered near Aberfoyle by Henderson (1938) and was later traced by Anderson (1947) along the Highland Border from Stonehaven to Arran. Its presence was deduced from graded bedding which showed that the Aberfoyle Slates in the core are older than the Leny and Ben Ledi Grits which form the flanks. It is now shown, from cleavage bedding relations combined with way-up evidence that, in the Callander area, this structure cannot have the form envisaged by Anderson. It closes downwards and is a synform.

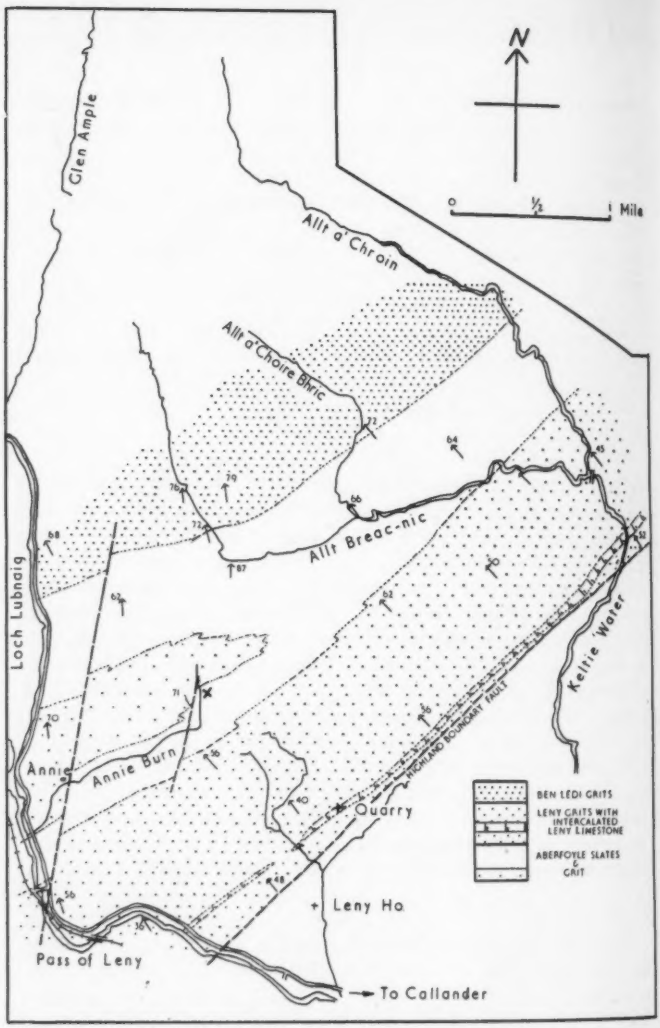
The downward-facing structures described in this paper were discovered and have already been described in other parts of the Highland Border by Professor R. M. Shackleton (1956).

SUCCESSION

The order of superposition in the Dalradian rocks of the Highland Border determined by Anderson (1947) is, from youngest beds downwards:—

4. Upper Leny Grits
3. Leny Limestone Group
2. Lower Leny Grits
1. Aberfoyle Slates

Leny Grits ≡ Ben Ledi Grits



TEXT-FIG. 1.—Geological sketch-map of the Dalradian rocks near Callander.

This succession has been confirmed in the Callander area by the author from a large number of observations of graded and current bedding.

Aberfoyle Slates

The widest and most conspicuous band of slates in the Callander and adjacent areas, mapped by the Geological Survey, can clearly be traced along the strike to the Aberfoyle Slates of the type-locality. In each of these areas they are dominantly purple or red near their southern margin, while the northern part of the outcrop contains mainly grey and grey-green slates.

The rocks referred to as the Aberfoyle Slates in this paper include the " Aberfoyle Slates " of Anderson, a group of slates (herein called the Annie Burn Slates) considered by Anderson to be intercalated in the Leny Grits and a series of grits that occurs between the two slate outcrops in the western part of the area.

The " Aberfoyle Slates " shown on Anderson's map are mainly grey-green slates with intercalated grits and calcareous bands. Purple slates occur near the junction with the Ben Ledi Grits in the western half of the area only; this horizon appears to wedge out between Allt Breac-nic and Allt a' Choire Bhric.

The Annie Burn Slates are purple and grey-green slates with thin intercalated grits and calcareous bands. Field evidence shows that the outcrop is wider than that shown by Anderson and that it can be traced along the strike for some distance to similar rocks in Allt Breac-nic.

The outcrop of the " Aberfoyle Slates " converges north-eastwards towards that of the Annie Burn Slates, leaving a wedge-shaped mass of grits between the two in the western part of the area. The relation of this wedge of grits to the slates is uncertain. Good way-up evidence is lacking except at two localities near the southern margin of the wedge. Graded bedding in the grits 450 yards south-west of Annie and current bedding in slates 350 yards north of the sharp bend in Annie Burn (i.e. at *X* in Text-fig. 1) show that the slates of Annie Burn are younger than the grits. The relation between these grits and the main band of Aberfoyle Slates is obscure, but evidence presented later indicates that the grits are older than the slates. The exact junction between grits and slates is everywhere difficult to determine because lithological boundaries are gradational; the junction shown on the map is consequently only approximate. The folded nature of the junction is inferred from minor folds in both slate and grit.

The Annie Burn Slates and the main band of the Aberfoyle Slates are, therefore, one and the same horizon. The wedge of grits, although included in the slate series for the present, is actually older.

The thickness of the grits is uncertain due to folding and the absence of a base. The present apparent thickness of the slates is 3,000 feet on the northern limb and 1,100 feet on the southern limb.

Lower Leny Grits

These are grey-green and light grey grits with intercalated grey and purple slates and beds of banded silty slate and purple grit. Nearly continuous stream sections show that despite some variation in dip, the grits dip constantly to the north-west and contain few minor folds. Many observations of graded bedding, in units 1–3 feet thick, show that these rocks are inverted and younger than the Aberfoyle Slates.

Grey-green grits are the dominant type of grit. They contain variable proportions of subangular to subrounded quartz grains having dimensions of the order 0·1 mm. to 1 cm., calcic oligoclase in varying amounts (0·5 per cent to *ca.* 10 per cent by volume), perthite (0 per cent to *ca.* 8 per cent by volume)—frequently highly altered; and a ground-mass of " rock powder " (quartz and feldspar ?) and green " chloritic " material.[1] Chlorite occurs also as larger flakes (up to *ca.* 0·5 mm. long) frequently intergrown with muscovite; whether these are detrital or metamorphic is uncertain. Accessory minerals include zircon, sphene, tourmaline, and iron ore (" limonite ").

Inequidimensional quartz grains, frequently showing undulose extinction and ruptural strain-shadows, usually show a preferred dimensional orientation with their longest axis or longer axes lying parallel to a crude cleavage marked by bands of " limonite " and " chloritic " material. Three quartz fabric diagrams of specimens from the Lower Leny Grits were prepared to determine whether a depositional or tectonic fabric existed. The diagrams showed no apparently significant preferred orientation and are not reproduced here.

Light grey grits are common but are more characteristic of the Upper Leny Grits and are described below. Purple grits, like the associated purple slates, owe their coloration to the presence of considerable amounts of haematite. Purple grits examined in thin section differ from the grey-green variety in containing haematite, carbonate, and as a rule less feldspar. Grey-green and purple slates associated with these grits owe their colour to the relative abundance of green clay minerals and haematite respectively. No detailed study of the petrology of the slates has been undertaken.

The thickness of the Lower Leny Grits is *ca.* 3,000 feet.

Leny Limestone Group

The Leny Quarry, 1,000 yards north-north-west of Leny House, is the type-locality for the Leny Limestone, where Pringle (1939) found trilobites which were identified by Dr. J. C. Stubblefield and considered to indicate a Middle Cambrian age. The limestone is light

[1] The term " chloritic " refers to the green clay-mineral matrix.

grey with graphitic partings and is associated with black limestone bands, graphitic slates, dark grey and light grey slates. This association of rocks, for which the author proposes the name Leny Limestone Group, forms a stratigraphical unit distinct from the Leny Grits to the north-west and south-east.

The Leny Limestone Group is well exposed in the Keltie Water and the Leny Quarry, where its junctions with the Upper and Lower Leny Grits respectively are seen.

In the Keltie Water and one of its tributaries, Allt na Mna Ruaidhe, the junction between the black slates of the Leny Limestone Group and grey and purple slates of the Upper Leny Grits is sharp, but there is no evidence of a structural break. Graded bedding in grit bands close to the junction shows that the Upper Leny Grits are younger than the Leny Limestone Group.

The junction between the Leny Limestone Group and the Lower Leny Grits is not seen in the Keltie Water section, but is well exposed in the Leny Quarry. Here, graphitic slates with thin limestones (*ca.* 2-4 inches thick) can be seen to pass structurally upwards into grey and purple slates and thence into grey slates with light grey grits. Immediately north of the quarry, graded-bedding in exposures of grit shows that the Lower Leny Grits are older than the Leny Limestone Group.

This evidence confirms Anderson's conclusion, based on evidence obtained elsewhere along the Highland Border, that the Leny Limestone and its associated slates are intercalated in the Leny Grits.

Polished and striated graphitic surfaces and drag folds in this group, compared with the rather uniform, almost unfolded succession of grits on each side, indicates that the Leny Limestone Group has behaved as a movement- or " lubrication "-surface during folding.

The approximate thickness of this group is *ca.* 100 feet in the Leny Quarry and *ca.* 200 feet in the Keltie Water.

Upper Leny Grits

Anderson placed those rocks stratigraphically above the Leny Limestone Group (as herein defined) in Bute and Arran, in the Upper Leny Grits, but he has not described the occurrence of Leny Grits younger than the Leny Limestone Group in the Callander area.

These rocks are mainly light grey, brown weathering grits containing iron-stained (sideritic ?) carbonate, together with some grey-green grits and grey slates. Anderson (1947) has compared the light grey grits with the Margie Grits of Angus and Kincardine. Like the grey-green grits, the relative proportion of quartz to ground-mass is highly variable and inequidimensional quartz grains are frequently aligned parallel to a crude cleavage. Feldspar is usually less abundant

than in the grey-green grits. The ground-mass is largely carbonate (sideritic ?) with white mica which may be intergrown with a little chlorite. Iron ore (" limonite ") and leucoxene associated with carbonate form streaks which pass round the quartz grains and impart a crude cleavage to the rock. Accessory minerals include sphene, zircon, and tourmaline.

The greater proportion of light grey to grey-green grits distinguishes this series from the Lower Leny Grits. Many observations of graded bedding show that the Upper Leny Grits are younger than the Leny Limestone Group. The dip is to the north-west, and graded beds face constantly south-east, indicating that the whole succession as far as the Highland Boundary Fault is inverted. This evidence disproves Anderson's conclusion that the Leny Limestone is contained in a syncline in the Keltie Water (Anderson, 1947, pp. 494, 495) and that the grits south of the Leny Limestone are equivalent to those north of that group.

Ben Ledi Grits

These rocks are similar to those of the Leny Grits in their mineralogy, textures, and the occurrence of graded bedding. Thin sections of typical grey-green grits show the same great variation in the proportions of minerals that is seen in the Leny Grits. Quartz grains are usually subangular, though in many cases some recrystallization has occurred producing secondary growth and intergrowth of adjacent grains. Plagioclase (calcic oligoclase) and perthite are common in the grey-green grits. The matrix of chlorite and " chloritic " material imparts the green colour to the grey-green rocks. Light grey carbonate-bearing grits are common.

However, the Ben Ledi Grits do differ from the Leny Grits in that no purple slates and grits have been found, the Leny Limestone Group does not reappear, and the junction with the Aberfoyle Slates is interbedded east of Allt Breac-nic, while that between the Aberfoyle (" Annie Burn ") Slates and the Leny Grits is sharp.

The absence of purple rocks in the Ben Ledi Grits here is believed to be an original difference. The high content of iron in these rocks compared with the apparently lower content in the green-coloured rocks (which are sometimes " limonite "-stained, but this is probably secondary) indicates that the purple rocks are (in part) oxidate sediments. Purple slates do occur, however, in the Aberfoyle Slates near their junction with the Ben Ledi Grits in the western part of the area; this would rule out any suggestion that the difference was due to the increase in metamorphism towards the north-west.

Recrystallization of quartz grains increases northwards as the rocks approach the biotite zone of metamorphism. The recrystallization

appears to be related to movement along a set of shear planes and produces a pseudo-bedding which cuts the true bedding obliquely. It would appear that much of the banding in the Ben Ledi Grits north of this area is the product of metamorphic differentiation.

The absence of the Leny Limestone in the Ben Ledi Grits of this area may be due to squeezing out during movement. The relative incompetency of the Leny Limestone Group compared with the grits and the apparent increase in deformation in the Ben Ledi Grits compared with the Leny Grits would account for its absence.

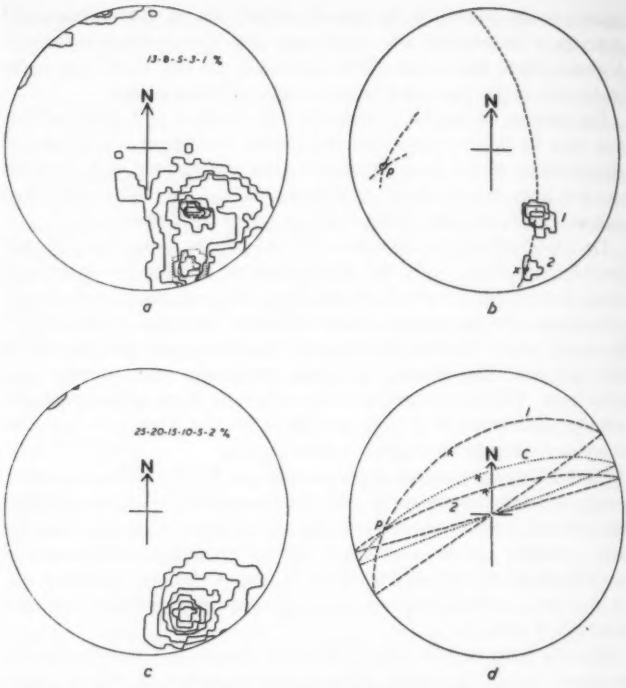
The interbedded junction with the Aberfoyle Slates east of Allt Breac-nic compared with the sharp junction between the Aberfoyle Slates and the Leny Grits is attributed to facies changes. On a small scale, facies changes can be observed in the Aberfoyle Slates of Allt Breac-nic, where thin bands of fine grit wedge out and pass into more slaty grit and thin streaks of purple slate may pass laterally into green slate. That such changes could occur on a large scale is probable and the postulation of a large amplitude for the Aberfoyle Anticline to account for a facies change is unnecessary.

Graded bedding near the junction with the Aberfoyle Slates is poor, though several examples in Allt Breac-nic recorded by Anderson (1947) show that the steep north-north-westerly dipping Grits face north-west. Further up the stream the quality of grading improves and many graded units show that the Ben Ledi Grits are right-way up, i.e. they face north-north-west, and are, therefore, younger than the Aberfoyle Slates.

Both the Leny and Ben Ledi Grits are, therefore, younger than the Aberfoyle Slates, and since there is no apparent structural break between the Aberfoyle Slates and the grits on either side, the author follows Anderson in correlating the Leny and Ben Ledi Grits.

Structures

The correlation of the Leny and Ben Ledi Grits whose basis has been outlined above implies that they form the opposing limbs of a fold that has a core of the older Aberfoyle Slates. From such evidence obtained elsewhere, Henderson (1938) concluded that these rocks were folded into an anticline which he called the Aberfoyle Anticline. However, the observation that the core of a fold is formed of older rocks does not necessarily lead to the conclusion that the fold is a simple anticline. The nature of a fold in structurally complex areas cannot be determined by way-up evidence alone, but only by combining this with structural evidence, and it has been proposed that the Aberfoyle Anticline closes downwards (see Shackleton (1956)). The structural data bearing on this proposition, in the Callander area, are presented below.



TEXT-FIG. 2.—Equal area projections (lower hemisphere).

(*a*) Contoured diagram of 230 bedding poles (full lines). Superimposed in this are the 40 and 20 per cent contours of thirty-one bedding poles in the Ben Ledi (dotted lines) and the 22 and 19 per cent contours of sixty-three bedding poles in the Lower Leny Grits (dashed lines).

(*b*) Pole of great circle (*p*) passing through maxima corresponding to Leny Grits (2) and Ben Ledi Grits (1).

(*c*) Contoured diagram of 200 cleavage poles.

(*d*) Great circles corresponding to "modal" cleavage plane (*c*), bedding in Leny Grits (2) and Ben Ledi Grits (1).

Bedding

The regional dip of the bedding is towards the north-west or north-north-west; the beds south of the Aberfoyle Slates dip less steeply than north of that group. This relation is shown in Text-fig. 2*a* in which bedding poles, measured mainly in the grits, have been plotted on the lower hemisphere of an equal-area projection. Two maxima occur: maximum 1 appears to correspond mainly to dips in the Leny Grits while maximum 2 appears to correspond to dips in the

Ben Ledi Grits. Separate plots of bedding poles in the Lower Leny Grits and the Ben Ledi Grits are included in Text-fig. 2*a*. These show, without doubt, that maxima 1 and 2 correspond to the " modal " dips of the Leny and Ben Ledi Grits respectively. This diagram indicates that the limbs of the fold converge eastwards and downwards, i.e. the fold plunges to the west-south-west.

In Text-fig. 2*b*, the point *p* is the pole of a great circle drawn through the two maxima. It is believed to indicate the plunge of the fold which is, therefore, 24° to the west-south-west.

Cleavage

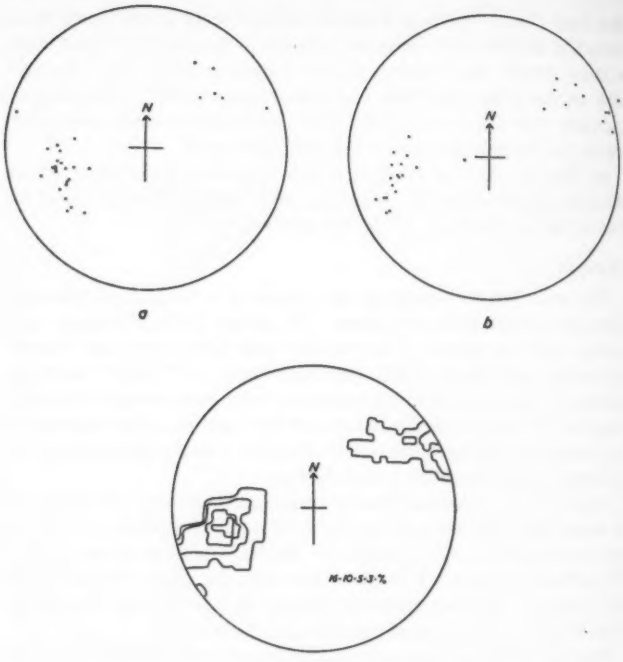
This structure is widespread and occurs as a conspicuous fracture-cleavage in both grits and slates. No folded fracture-cleavage such as was reported recently from the Ben Ledi Grits near Loch Katrine by Richey and Harry (1955) has been seen. A " slaty " cleavage, defined by the parallelism of secondary micaceous material has been observed in many slates, but only in thin section. This cleavage is cut and often slightly displaced by the later fracture cleavage (in this case more properly called a *slip cleavage*).

A plot of all measured cleavage poles on the lower hemisphere of an equal area projection is shown in Text-fig. 2*c*. There is a 25 per cent maximum which represents a " modal " cleavage plane dipping 70° north-north-west. This plane intersects the angle formed by the two " modal " bedding planes of Text-fig. 2*a* (see Text-fig. 2*d*) though it lies closer to the plane of the Ben Ledi Grits.

Text-fig. 2*d* shows diagrammatically that cleavage in the Leny Grits is steeper than the bedding, while in the Ben Ledi Grits the opposite relation holds. Every exposure examined in the grits confirms this relation. The figure further shows that the plunge of the major fold axis corresponds to the plunge given by the cleavage/bedding intersection on each limb. These two sets of observations, together with the observed parallelism of cleavage with the apical planes of the minor folds in both slates and grits, lead to the conclusion that the cleavage lies parallel to the apical plane of the major structure.

Minor Folds and Lineation

Minor folds are much more widespread in the Aberfoyle Slates than in the Leny and Ben Ledi Grits. The twenty-nine fold axes plotted in Text-fig. 3*a*, therefore, come largely from the Aberfoyle Slates. There is a concentration of points plunging between 20° and 30° to the west-south-west. The plunges of twenty-eight measured cleavage/bedding intersections (Text-fig. 3*b*) from the Aberfoyle Slates and slate-grit junctions in the grits show a close correspondence with those of the minor fold axes, though there is a slight tendency towards



TEXT-FIG. 3.—Equal area projections (lower hemisphere).
(*a*) Twenty-nine fold axes, mainly from the Aberfoyle Slates.
(*b*) Twenty-eight measured cleavage/bedding intersections.
(*c*) Composite contoured diagram of twenty-nine fold axes, twenty-eight measured and fifty-two calculated cleavage/bedding intersections.

a girdle development. This slight girdle development is brought out still further in Text-fig. 3*c*, which is a composite contoured diagram of measured lineations and fold axes together with fifty-two cleavage/bedding intersections, each calculated from the measurement of cleavage and bedding in one exposure.

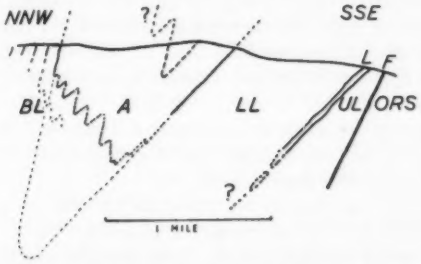
The girdle development indicates an apparent partial rotation of plunge about an axis inclined at a low angle to the south-south-east. There is no evidence for a major axial plunge culmination or depression in the area though, in the slates exposed in Allt Breac-nic, which runs subparallel to the strike, there are many examples of minor variations in plunge.

The maximum of Text-fig. 3*c* corresponds fairly closely with the

plunge of the fold axis determined by the intersection of the " modal " bedding and cleavage surfaces of Text-fig. 2*d*, and is further evidence of the unity of the structures in the area; it is inferred that the minor folds are geometrically and genetically related to the major structure.

Conclusions

(1) Observations on graded and current bedding show that the Cambrian Leny Limestone in this area is intercalated in an inverted succession of Leny Grits (Upper Dalradian) and not contained in a syncline as previously supposed.



Text-fig. 4.—Diagrammatic cross-section passing through Leny Quarry at *L*. A = Aberfoyle Slates; LL = Lower Leny Grits; L = Leny Limestone Group; UL = Upper Leny Grits; BL = Ben Ledi Grits; O.R.S. = Old Red Sandstone; F = Highland Boundary Fault.

(2) The observation that both the Leny and Ben Ledi Grits are younger than the Aberfoyle Slates confirms Anderson's observations and his conclusion that the two grit series can be correlated.

(3) The Annie Burn Slates (of this paper), considered by Anderson to be intercalated in the Leny Grits, are thought to represent the outcrop of the Aberfoyle Slates on the southern side of the Aberfoyle Anticline.

The wedge-shaped area of grits occurring within the outcrop of the Aberfoyle Slates in the western part of the area is believed to occupy the core of the Aberfoyle Anticline. It was stated earlier that the relations between these grits and the Aberfoyle Slates were uncertain, though one example of graded and one of current bedding on the southern margin indicated that the Annie Burn Slates were younger than the grits. The relation between these grits and the Aberfoyle Slates on the northern limb is more obscure, but graded bedding in small-scale folds in slate near the northern junction of the grits shows that the beds face down the apical plane, and since this relation has

been found elsewhere in the area the grits must be older than the Aberfoyle Slates of the northern limb.

(4) Field observations and data presented in the statistical diagrams show that the cleavage lies parallel to the apical plane of the Aberfoyle Anticline and that the limbs of the fold converge eastwards and downwards, i.e. the fold closes downwards and plunges to the west-south-west. The form of the fold is illustrated diagrammatically in Text-fig. 4. The finer line separating the Leny and Ben Ledi Grits from the Aberfoyle Slates shows the form of the fold when it is assumed that the nose and limbs are unfolded. However, the apical plane of such a fold would not be as steep as that indicated by the " modal " cleavage plane of Text-fig. 2*c*. The observed folding and the dominance of beds dipping more steeply than the cleavage in the Aberfoyle Slates on the northern limb of the Aberfoyle Anticline, indicate that the form of the fold is similar to that shown by the heavy lines in Text-fig. 4.

The Aberfoyle Anticline is, therefore, a synform. It cannot be a syncline since its core is older than the flanks and the beds face down the cleavage and apical plane.

The structure, therefore, is not a normal anticline as described by Anderson (1947), but a more complex structure that closes downwards and plunges to the west-south-west. This conclusion agrees with that of Shackleton (1956), though the evidence for the downward-facing structures presented here is different from that used by him.

Acknowledgment.—The author would like to thank Professor R. M. Shackleton for suggesting the problem and for much helpful guidance and criticism, and Mr. T. G. Miller for reading the manuscript and making many useful suggestions. The field work was carried out with the aid of grants from the research funds of the University of Liverpool and University College of North Staffordshire.

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A Note on the Occurrence of Rhythmic Layering in the Eilean Mhuire Sill, Shiant Isles

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(PLATE IX)

Abstract

This note records a unique instance of rhythmic layering which is likely to have an important bearing on the interpretation of such layering in general.

In view of the vital importance to igneous petrogenesis of a fuller understanding of rhythmic layering, the following brief account of this phenomenon in Eilean Mhuire has been written in advance of a detailed investigation. It may have an important bearing on current research outside the field of inquiry which is the writer's main concern at the present time.

For a number of years the writer and his colleagues have been investigating picritic rocks in the Shiant Isles, Skye, and elsewhere. The members of the first and third expeditions to the Shiant Isles made only brief excursions by rowing boat from the main island to the south-east end of Eilean Mhuire, the most easterly island of the group. Two research students (P. R. Hooper and Jane Daly), members of the fourth expedition led by Mr. Douglas Scott, reinvestigated it very thoroughly. In addition to the writer's own observations he has drawn freely from those of R. Johnston (in charge of the second and third expeditions) and P. R. Hooper.

No evidence of more than one sill could be discovered during the final detailed survey of the island. This is not in accordance with Walker's observations (1930). Hooper and Daly had the benefit of Walker's pioneer work, of the observations and collections of the two earlier expeditions, and they probably spent a longer period on the island than that of all previous visits added together. That the intrusion is the upper part of a sill can be supported, as Walker discovered, by the occurrence of an upper contact with flat-lying Jurassic marls, mainly along the top of the north-eastern cliffs. It seems quite probable that on Eilean Mhuire we have the downfaulted top of the much better known crinanite-picrite sill of Garbh Eilean-Eilean an Tighe. To prove this it would be necessary to undertake a deep boring.

It was Sir Archibald Geikie (1897) who discovered the layering and observed that it consisted of alternations of layers largely feldspathic with others rich in ferromagnesian minerals and iron ore. He also noted that " in some layers the long black prisms (of augite) are arranged in a general parallelism with the banding ". Murray (1954) recorded

the fact that this augite occurred in a zone not only layered but also laminated. Petrographical descriptions of the rocks were published by Walker.

Apart from the shore platform, which is mainly uniform crinanite, much of the exposed, 200 feet thick, section is a medium- or coarse-grained rock conspicuously layered in a number of places. The layers have the familiar repetition and rhythm involving basal enrichment in heavy minerals grading upward into a more felsic facies (Plate IX, fig. 2) sharply bounded against the succeeding layer in which the same phenomena are repeated. This rhythmic layering is accompanied by extremely well-developed igneous lamination (Plate IX, figs. 1 and 3) comparable with the classical occurrence of this phenomenon (Wager and Deer, 1939). Geikie did not realize that the orientation of the minerals, mainly columnar clinopyroxene and tabular plagioclase, was planar. In the Howford Bridge sill Tyrrell (1928) recorded a sub-parallel arrangement of narrow feldspar laths. In view of the possibility that this might represent a similar but less well-developed lamination, the writer examined this sill but found no evidence of rhythmic layering.

A pyroxene, collected by the writer from a pyroxene-rich laminated layer on the shore at the bottom of one of the main layered zones on the southern part of the island, was analysed by Murray (1954). Through the kind co-operation of Dr. S. R. Nockolds the analysis was recently completed in Cambridge by the spectrographic determination of the trace elements.

The full analysis can now be quoted:

	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO
Wt. %	50·29	1·47	1·23	1·03	11·75	0·25
	MgO	CaO	Na_2O	K_2O	H_2O-	H_2O+
	12·47	21·07	0·49	tr.	0·05	0·27

	Ga	Cr	V	Li	Ni	Co	Sc	Zr	Y	Sr
p.p.m.	5	10	300	—	10	35	75	90	55	20

This pyroxene has a higher percentage of SiO_2 and a correspondingly lower percentage of Al_2O_3 than any other analysed pyroxene from the Shiant Isles. It is also distinctive in its relatively low amounts of Cr, V, Ni and Sc. The aegirine molecule is not significantly represented. It must, in fact, be emphasized that in the layered zone the pyroxene is an augite.

There is a marked change in the textural relation of the pyroxene (and to a less obvious extent in the textural relation of the olivine) upward from the shore platform into the layered zone. In this zone it becomes virtually non-ophitic in relation to feldspar, columnar in habit and often idiomorphic. It could be regarded as " primary " with all

that is implied by this term in the case of major layered intrusions (Wager and Deer, 1939; Brown, 1956). On the other hand, the clinopyroxene that occurs below the layered zone cannot be interpreted as "interprecipitate" (sensu stricto); it is simply ophitic.

It is a well-known fact that in many basic alkaline sills the clinopyroxene may occur as idiomorphic or sub-idiomorphic crystals. Even in the same thin section it may change from an ophitic relation to plagioclase at one point to a non-ophitic relation at another point, where there is a relative concentration of analcite. This variability in the pyroxene-plagioclase relations in such rocks seems clearly to reflect, in many cases, a variability in concentration of water. That a high concentration of water in the Eilean Mhuire sill has played a significant rôle in the development of the layering and lamination seems beyond dispute and these phenomena represent an almost precise replica of the layering and lamination of certain gabbroic intrusions in which there is no evidence that water concentration has been an important factor. It is, of course, possible that the high degree of liquidity essential for the development of rhythmic layering and lamination can be achieved in more than one way.

Walker observed that relatively heavy rocks rich in clinopyroxene and iron ores occur at the highest levels on the island thus discounting gravity, according to him, as a factor in the differentiation of the sill. Instead, he suggested a mechanism of autointrusion of the feldspar- and zeolite-rich facies (referred to as analcite-syenite) into the more pyroxene-rich facies. This concept does not explain important characteristics of the layering, such as the upward gradation of dark into light facies, and the general complementary relation of the one type to the other. The light and dark facies also occur as irregular patches but, if autointrusion is to be invoked in such cases, the dark facies could equally well be regarded as intrusive into the light.

Hooper would prefer to restrict the name analcite-syenite to the comparatively small veins rich in alkali feldspars, analcite (and/or nepheline) and aegirine-augite (and/or aegirine). The main feldspathic facies, forming about 30 per cent of the layered zone, could then be discriminated as augite-analcite-andesinite and, where the augite occurs in almost negligible amount, as analcite-andesinite. Its genetic counterpart in non-alkaline (tholeiitic) intrusions is probably the anorthositic facies.

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EXPLANATION OF PLATE IX

FIG. 1.—Igneous lamination in layered zone at south-east end of Eilean Mhuire. Many of the tabular plagioclase crystals appear black owing to replacement by serpentine. Olivine is totally replaced by serpentine. The other components are mainly clinopyroxene and iron ore. The plagioclase is also considerably replaced by analcite. Analcite and other zeolites occur in the groundmass. Ordinary light, × 3.

FIG. 2.—Hand specimen showing a complete layer with concentration of the heavy minerals at the bottom. Some lamination defined by columnar pyroxenes can also be seen, × $\frac{2}{3}$.

FIG. 3.—Igneous lamination at the bottom of a layer in layered zone at south-west end of Eilean Mhuire. Columnar clinopyroxene (analysed), iron ore and dark serpentine are the principal constituents. Ordinary light, × 5.

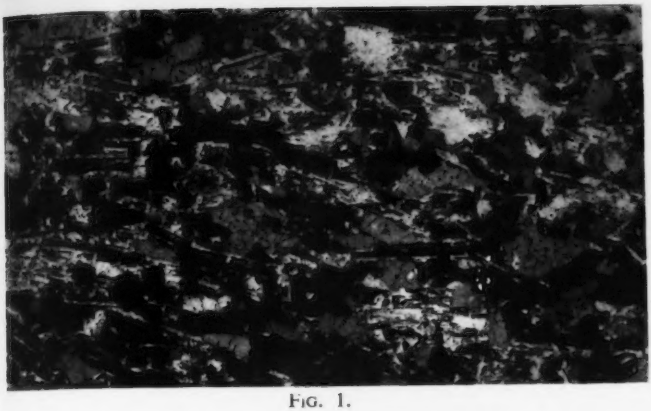


FIG. 1.

FIG. 2.

FIG. 3.

LAYERING IN THE EILEAN MHUIRE SILL.

Salterolithus caractaci (Murchison) from Caradoc Strata near Welshpool, Montgomeryshire

By R. Cave

(PLATE X)

Abstract

Material belonging to the genus *Salterolithus* has been examined from Trilobite Dingle, Welshpool, and it is found that *S. caractaci* and *S. intermedius* (Wade 1911) are conspecific, the older name taking priority. Trilobite Dingle is the type locality for *S. intermedius* and also for the restricted species *caractaci*. A new variety is established for the forms occurring slightly higher in the sequence than *S. caractaci*.

Stratigraphy

The section in Bron-y-Buckley Wood (Trilobite Dingle), Welshpool (Grid Ref. 32213080), exposes about 150 feet of fawn, grey, olive-green, and red-stained mudstone in a small stream following approximately the line of the strike. These beds were referred to as Trilobite Dingle Shales by Wade (1911, p. 420) and by Bancroft (1933 in his table). The localities are spaced throughout the section, the low numbers occurring at the high end of the succession in the northern part of the dingle (Text-fig. 1). The beds are of Caradocian age belonging to the Harnagian Stage (Bancroft, 1929, p. 67).

About 100, mostly incomplete, specimens of *Salterolithus* were collected from every " fruitful " exposure, but some horizons proved better than others both for preservation and numerical yield. Locality λ35 was a notably good one. Though the size of the specimens varied greatly, as far as could be ascertained they had reached the adult stage.

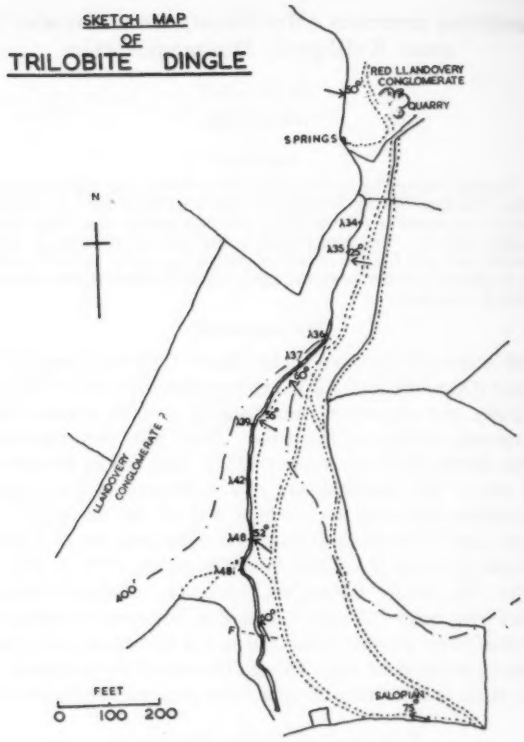
Variation in Fringe Structure

From measurements carried out on the pitted fringes and the cephalic widths (Appendix A), it was observed that:—

(1) The number of pit rows and the number of pits in the rows differed, sometimes greatly, between individuals of any one horizon.

(2) The variation in width of the cephalon did not bear any relationship to the variation in the number of pits on the fringe.

The notation used in describing the pits of the fringe follows Bancroft (1929), pp. 68–72). To illustrate the above points the following figures are selected from those given at the appendix, first from locality λ35, virtually representing a single bedding plane, then from the combined collection from localities below λ35, representing about 40 to 50 feet of beds.



TEXT-FIG. 1.—Sketch-map of Trilobite Dingle, Welshpool.

(1) *Specimens from locality* λ35 (see Text-fig. 1).

	Range.	*Mode.*
E_1 . .	25–29	27
I_1 . .	24–29	26
E_2–E_4 . .	30–68	48

Cephalic width from 1·0 cm. to 2·92 cm. showing no correlation with the number of pits E_2–E_4 inclusive, e.g. specimens B699, D301, and B715.

(2) *Specimens from localities below* λ35, i.e. λ36 to λ41, λ44, λ45, λ47 to λ48 i (see Text-fig. 1).

	Range.	*Mode.*
E_1 . .	26–29	27
I_1 . .	23–28	25–26
E_2–E_4 . .	35–79	58

Cephalic width from 1·32 cm. to 3·13 cm. again showing no relationship to the number of pits in E_2 to E_4 inclusive, e.g. specimens 345*b*, C684, 316, and B748.

(1) While no doubt is cast on the value of the pitted fringe as a specific character within the genus *Salterolithus*, when differentiating species the properties of the whole population have to be considered and not merely the best available specimen.

(2) There is a noticeable difference between specimens from localities λ34, λ35, and λ32 from the top of the succession and those from localities at lower horizons. The specimens from the higher group of localities appear to be a variety of the species encountered in the lower group. This variety shows a reduction in the development of E_3 and a reduction in the size of the genal prolongation—" ear ".

The specimens of *S. caractaci* figured by Murchison (1839, pl. 23, figs. 1 *b* and *c*: G.S.M. Geol. Soc. Coll. 6829, 6834) and that of *S. intermedius* (Pl. X, fig. 3), figured by Wade (1911, pl. xxxvi, fig. 1; G.S.M. 28379, here chosen as lectotype), can be matched on lithological grounds with others from the lower group of localities and their measurements are listed below:—

Name	Specimen No.	Pits				Cephalic width (cm.)
		E_2–E_4	E_1	I_1	E_3	
S. caractaci . .	6829	52	29	29	c	3·20
S. caractaci . .	6834	76	27–28	28	a + E_4	2·85 approx.
S. intermedius .	28379	55 approx.	28–29	25	a	2·10

The above figures also show that these specimens comply with the analysis of the collection from the lower localities and that although their individual pit characters differ slightly they belong to the same population and species. *S. intermedius* is therefore a subjective synonym of *S. caractaci*.

Individuals from this section showing certain extreme pit characteristics have been identified with other species, e.g. forms like *S. harnagensis* Bancroft (Bancroft, 1929, p. 81) and *S.* cf. *intermedius* (Wade) (Bancroft, 1949, p. 293). It is suggested that these identifications also relate to individuals of *S. caractaci* as here interpreted.

Trinucleus fimbriatus Murchison and *Telaeomarrolithus* [*Trinucleus*] *radiatus* (Murchison) are recorded by Murchison (1839, p. 660, and 1867, explanation of plate 4, fig. 8) as occurring near Welshpool and from Trilobite Dingle, Welshpool. The lithology of these specimens (Murchison, 1839, pl. 23, figs. 3*a*, *b*, and 2) is unlike anything seen in the Welshpool area and the labels accompanying the specimens

indicate that they came from Builth (Whittard, 1956, p. 65, and Williams, 1948, p. 85).

No horizon below the Harnagian is known to be exposed at Welshpool.

Family, TRINUCLEIDAE Emmrich, 1844
Genus, SALTEROLITHUS Bancroft, 1929
Salterolithus caractaci (Murchison, 1839)

Trinucleus caractaci Murchison, 1839, p. 659, pl. 23, figs. 1*a*, *b*, *c* (non *d*, *e*, and *f*).
T. concentricus Murchison, 1854, 1867, and 1872, pl. iv, figs. 2, 4, and 5.
T. intermedius Wade, 1911, p. 449, pl. xxxvi, figs. 1 and 2.
Salterolithus caractaci Bancroft, 1949, p. 293.

Lectotype.—Here chosen as the original of Murchison, 1839, pl. 23, fig. 1*b* (Pl. X, fig. 5).

Though Murchison (1839, p. 659) stated that his figures of the species come from specimens collected by him "in reddish and blackish, sandy shale, in a little dingle west of Welch Pool Church", the labels attached to his specimens in the Geol. Soc. Coll. preserved in the Geological Survey Museum indicate that the originals of his pl. 23, figs. 1 *a* and *c* (Nos. Geol. Soc. Coll. 6828 and 6834) come from Welshpool and the originals of figs. 1 *d*, *e*, and *f* (Nos. Geol. Soc. Coll. 6830, 6832, and 6831) come from Wistanstow, Shropshire. The original of fig. 1*b* (Geol. Soc. Coll. 6829) has no affixed locality. Lithologically the specimen numbered 6829 resembles very closely fossils from localities in the southern portion of Trilobite Dingle and it is assumed to come from the Welshpool Trilobite Dingle section.

All these specimens rank as syntypes of *S. caractaci* (Murchison). Bancroft, 1949, however, excluded the originals of figs. 1 *d*, *e*, and *f* from his concept of the species, but did not select a lectotype. Because of the preservation and the fact that the specimen No. Geol. Soc. Coll. 6829 is the most representative it is here selected as lectotype.

Locality.—Trilobite Dingle, Bron-y-Buckley Wood, Welshpool. Probably from the olive-green mudstones in the southern portion of the Dingle about 650 feet south-south-west of the quarry in red conglomerate at the north end of the Dingle.

Diagnosis.—Glabella and cheeks smooth, convex but without marked inflation. Glabella long and tapering, with anterior broad and rounded. Axial furrows shallow, fringe broad produced into "ears" posteriorly. Fringe generally with three rows of pits external to the girder, E_3 often being defective laterally and with pits irregularly spaced in relation to pits of E_2. The number of pits external to E_1 has a mode of about 58.

Description.—Margin of the cephalon semi-circular. Glabella and cheeks smooth.

Glabella almost pear-shaped and moderately convex. In plan the anterior margin is broad and rounded, the lateral margins straight, convergent without meeting. Length nearly twice the maximum width, three times the height. In profile the anterior portion descends in a shallow convex arc to the pitted fringe, there producing a sharp angle with it of about 100°. Posteriorly the descent to the nuchal segment is neither so curved nor so steep, making an angle of about 30° with the plane of the fringe.

The cheeks are moderately swollen. In outline the posterior margin is frontally convex, receding from the occipital segment laterally and curving into the antero-lateral margin which is quarter-circular. The internal margin is defined by a rather shallow axial furrow and is gently concave producing an internal posterior angle of the cheek of about 60° to 70°, The antennary pits are shallow or absent.

The occipital segment is very narrow with the occipital furrow shallow, hardly distinguishable across the axial portion. There it gives rise to a strong thorn-like spine projecting posteriorly for a distance equal to the length of the glabella at an elevation of about 30° to the plane of the fringe.

The fringe is approximately of uniform width except posteriorly where it spreads behind the cheeks to produce a small complex of pits. Otherwise it represents just less than a quarter of the length of the cephalon. The dorsal plate is flat and horizontally extended, except in the postero-lateral portions where it is slightly depressed. In this posterior portion " ears " are quite well developed. The width of the fringe outside the girder is equal to or slightly greater than that inside the girder and along the posterior margin of the fringe, inside the girder, there exist about nine or ten pits.

There are four completely developed pit rows I_2, I_1, E_1, and E_2, while E_3 is sometimes complete and usually well developed. Occasionally the number of pits at the anterior of the fringe is in excess of the capacity of E_3 and the surplus is displaced outwards to form what might be termed an E_4 row. All pits on the fringe show a marked concentric arrangement, but pits internal to E_2 also show a radial disposition. Pits of E_2 and E_3 being smaller than those of the rows internal to them are irregularly spaced and do not continue the radial appearance outwards. Pits of E_1 and I_1 are of the same size and large; these rows are separated by a strong ridge representing the girder and I_1 is separated from I_2 by another but less noticeable ridge. Thus, I_1 gives the appearance of being depressed. I_3 is developed laterally on the slopes of the cheeks. The number of pits external to E_1 varies between 35 and 79 with a mode of about 58. In E_1 and I_1 the variation is 26 to 29 and 23 to 28 respectively, with modes of 27 and 25–26 respectively.

The lower lamella shows a conspicuous girder separating E_1 and I_1 well striated with terrace lines. A similar ridge separates I_1 and I_2.

The thorax consists of six well-defined segments, the pleurae are flat and horizontally extended. The segments are directed out laterally, with a slight backward curve at the extremities producing a short spine. The pleural grooves are strong and broad arising slightly behind the anterior internal corners of the segments and passing as almost straight lines diagonally across the segments. The axis is broad, one-quarter the width of the thorax, bounded by shallow axial furrows and divided by strong intrasegmental grooves. The segmental boundaries themselves are weak.

The pygidium is transversely arcuate to obtusely triangular. The length is about equal to the thorax and the two together are about as long as the cephalon. It is weakly divided by six pleural grooves. The sigmoidal curvature which was just apparent in the pleural grooves of the thorax is rapidly accentuated in passing back through the pygidium. The grooves are thus not parallel, but diverge laterally. Across the axis these grooves are indistinct and appear to divide into two sets, one swinging sharply forward about the mesial line, the other taking a straighter course. The pleural lobes are not plane but swollen in a zone adjacent to the axial furrows and again externally, producing a saddle along the middle regions.

The axis is broad, tapering backwards and defined laterally by very shallow axial furrows. It is ornamented by a criss-cross pattern of grooves previously mentioned of which there are at least nine sets. These are intersected by a low median ridge traversing the length of the axis but being more distinct at the rear.

Remarks.—The description of Bancroft (1929, p. 82) is not representative of the species and this he appears to have realized in his redescription (1949, p. 293) where he amended the statement: " many specimens are virtually four- (continuous) row forms " to read " E-region with three well-defined concentric rows, or abnormally with the outermost row (E_3) defective on the sides ".

Salterolithus caractaci var. *paucus* var. nov.

S. caractaci Bancroft, 1929, pp. 78 and 82.

Holotype.—Sedgwick Museum specimen A40879 (Pl. X, fig. 1).

Paratypes.—Sedgwick Museum specimens A46414 and A46415 (Pl. X, figs. 2*a* and 2*b*).

Locality.—No. λ35, 100 yards south of the small quarry in conglomerate (Text-fig. 1), in the stream at the north end of Trilobite Dingle, Grid Ref. E32213 N30810.

Diagnosis.—Differs from *S. caractaci* in that the pitted fringe consists of four more or less continuous rows of pits, two internal and

two external to the girder, with a fifth row anterior to the glabella as intercalations in E_2. " Ears " small.

The total number of pits external to E_1 has a mode of about 45, the mode for E_1 is about 17 and for I_1 about 25. Four pits of E_1 are usually external at the genal angles.

Remarks.—A defective specimen (Pl. X, fig. 2*a*) shows the healed, though still deformed, portion of the fringe, presumably resulting from an injury. The pit arrangement is modified though not entirely lost. The number of pits, too, is little altered though their size is much smaller than normal. The marginal suture is still complete having reformed on the damaged portion.

Grateful acknowledgment is made to Professor W. B. R. King under whose helpful guidance this work was carried out; to the Cheshire County Education Committee for financial awards making the work possible; to Dr. C. J. Stubblefield and Mr. R. V. Melville for helpful criticism of the manuscript, and to Professor W. F. Whittard for much useful discussion.

Appendix A

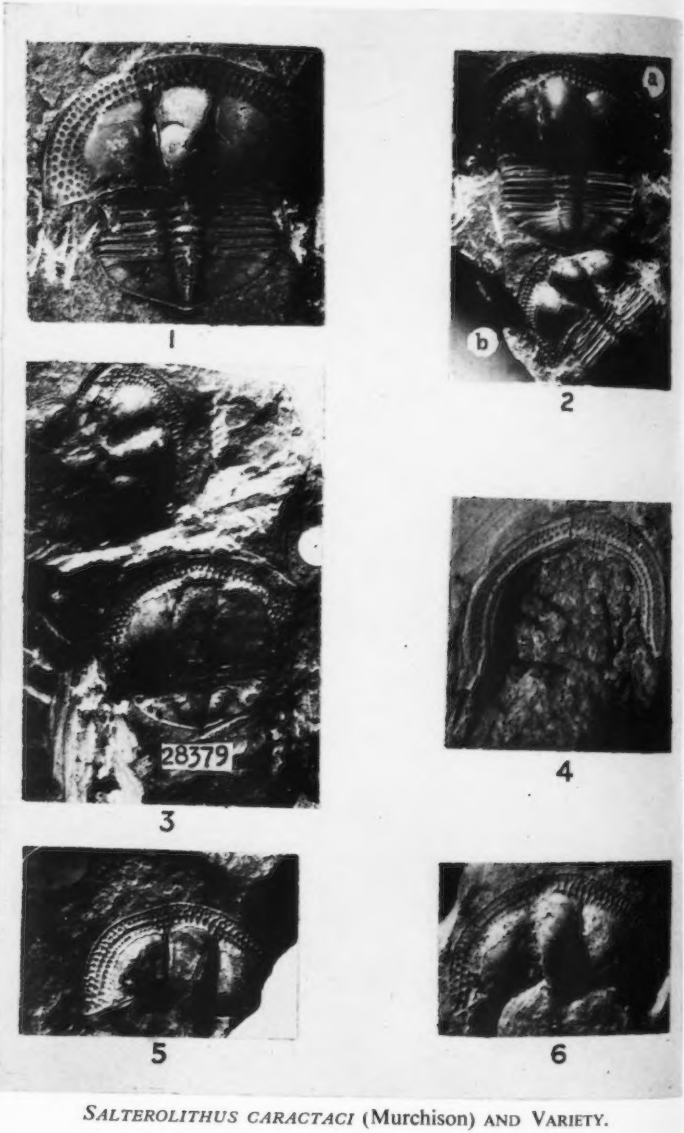
Explanation of notation used under column E_3

a = E_3 complete or nearly complete.
b = „ half complete.
c = „ present anteriorly and again antero-laterally.
d = „ present anteriorly.
e = „ present as a few intercalations in E_2 in front of the glabella.
f = „ absent.

Figures in brackets refer to the alternative lateral half of the fringe.

Locality	Specimen No.	Pits				Cephalic width (cm.)
		E_2–E_4	E_1	I_1	E_3	
λ48 i . .	D340	48–49	28–29	24–25	b	1·50
	D341				a	2·40
	D343	38–41	28–29		b	1·80
	D345				a	
	D346	63 app.	27 app.	25–26	a	1·42
	D347				c	
λ48 . .	361	42–52	27	26		2·12
	C685	49–53	27	26	a	2·24
	C684 i	41–43	27	27	e	2·80
	ii				a	
	D353	40 app.	26–27	26 app.	b–c	2·44
	D354				a	
	D357				a–b	
	D359	35(45)	27(27)	25	c	2·00
	D361				b	
	C683				a	2·88

Locality	Specimen No.	Pits				Cephalic width (cm.)
		E_2–E_4	E_1	I_1	E_3	
λ47 . .	345a	67	27(27)	27(28)	a	2·90
	b	46	27	26	b	3·10
	351	56 app.	26	26	c	
λ45 . .	333	46(50)	27(27)	24(23)	b	1·84
	B 748	59–60	26	25	a	1·32
λ44 . .	331		26	25	e	
λ41 . .	318	79	28	26	a	2·32
λ40 . .	316	70–71	26	26	a	1·98
λ39 . .	B 743	52–53	27(26)	25(26)	a	2·38
	B 744	70	26	23(24)	a	3·13
	B 747	63–64 app.	27	25	a	2·18
	D362				a	
	D363				b	
λ38 . .	312				a	
λ37 . .	B 732	63	27(27)	25(26)	a	2·34
	B 733				d	
	B 735				a	
	B 737a	60–61 app.	27	25	c	2·18
	B 739				b	
λ36 . .	B 728	39(41)	27(29)	24(26)	b	2·22
	B 729	60 app.	26–27	25	c	1·94
	B 725	58–60 app.	27(28)	25(25)	a	1·66
	B 720				a	
	C 664	74	29–30	25(28)	a + E_4	2·29
λ35 . .	B 697	34(31)	27(25)	26(24)	e	
	B 698	31				
	B 699	37–38	26	25	d–e	2·15
	B 701				d	
	B 708	30	24	23	f	1·30
	B 715 i	42(45)	25(24)	24(24)	b	1·30
	ii	67	27	29	a	1·00
	B 704	57	29	26	a	2·90
	B 710	47	25(26)	25(26)	b	2·54
	B 709	50(53)	27(26)	26(25)	c	1·28
	309	52	25–26	22(23)	c	2·09
	305				f	
	C 674	45	29–30	27	d	1·00
	C 680				f	
	D298	51	28	25	a–b	1·88
	D288	46	25	24–25	c	
	D300	43–45	27		b	1·52
	D293	44	26		d	2·42
	D295 i	47	27	23	c	1·08
	D296 i	40	26–27	25	e	1·77
	D301	31	27	26	f	2·92
	D302	68	29	27	a	1·84
	D303	41	27	27	d–e	1·70
	D304				e	
	D289	55	25–26	24	b	2·0 app.
	D293				f	



SALTEROLITHUS CARACTACI (Murchison) AND VARIETY.

Locality	Specimen No.	Pits				Cephalic width (cm.)
		E_2–E_4	E_1	I_1	E_3	
	D294				c	
	D295 ii				c	
	D296 ii				e	
λ34 . .	C528	40–45	25	24	d	1·12
	C529				f	
	C516				a	
	C518	53–54	26(26)	23(24)	c	2·37
	C520 i				f	
	ii				e	
	C525				f	
	C530				f	
	C521 i	34 app.	25	24	f	1·95
	C527				f	
	C526				e	
	C521 ii				e	2·10
λ32 . .	B675	54	27	24	b–c	2·18
	B681	47	27	24	f	1·15
	B688				d	
	B680 i				f	
	ii				d	
	B677				f	
	B691				f	

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EXPLANATION OF PLATE X

FIG. 1.—*Salterolithus caractaci* var. *paucus* var. nov. × 2, Sedgwick Museum A40879, from locality λ35.

FIG. 2.—*S. caractaci* var. *paucus* var. nov. × 1½. (*a*) Abnormal specimen, S.M. A46414 ; (*b*) S.M. A46415. From locality λ35.

FIG. 3.—" *S. intermedius* (Wade) " × 1, (lectotype) = *S. caractaci* (Murchison) Geol. Survey 28379. In red mudstone probably from the region of locality λ36.

FIG. 4.—*S. caractaci* (Murchison) × 2, showing ventral fringe plate. S.M. A46416, from locality λ36 in red mudstone.

FIG. 5.—*S. caractaci* (Murchison) × 1, showing dorsal fringe plate (lectotype). Geol. Survey, Geol. Soc. Coll. 6829.

FIG. 6.—*S. caractaci* (Murchison) × 1½. A plasticine cast showing the dorsal surface of the cephalic shield. The original is in red mudstone from locality λ39. S.M. A46417.

The Lustleigh Fault in North-East Dartmoor

By F. G. H. Blyth

Abstract

The north-eastern area of Dartmoor is traversed by a series of straight valleys which follow fault lines. One fault-system, which crosses the granite from near Lustleigh north-westwards to Sticklepath, is described in detail, and its relationships to structures in a wider area are briefly discussed.

THE main area of high moorland on Dartmoor lies to the south-west of a line which runs from South Zeal (east of Okehampton) by Chagford and North Bovey towards Bovey Tracey. To the north-east of this line the granite moorland is less conspicuous than to the west: the country is much cultivated and is traversed by deep valleys, with intervening uplands or ridges which in places rise to a little over 1,000 feet O.D. The marked contrast between this north-eastern tract and the higher western ground can be clearly seen on the 1-inch topographical map (sheet 175, 1946 edition). The contrast appears to have been noted over a century ago by Austen (1842, p. 477), who commented on " the great dome-shaped masses " such as Cawsand Hill, on the one hand, and on the other hand " the long vertical walls, with lines of ruin and confusion, constituting the wild scenery about Lustleigh, and along the road from Bovey to Moreton ".

In addition, the drainage pattern in the higher western area has a predominantly north–south trend, whereas the main valleys in the north-eastern tract trend between north-west and north-north-west. Several of them have noticeably straight courses where they follow fault lines. They were briefly mentioned by Clement Reid in the Newton Abbot Memoir (1913, p. 104)[1]: " Throughout the area around Newton Abbot and Moretonhampstead there is a remarkable development of straight parallel valleys having a north-westerly trend. This trend corresponds with that of most of the Tertiary faults in Devon, Cornwall, and Dorset. . . ." Two of these straight valleys were dammed between 1860 and 1884 in the construction of the Tottiford and Kennack Reservoirs of the Torquay Waterworks; and the 1913 Memoir also records that " disintegration of granite *in situ* into coarse sand " occurs " over considerable tracts, as at Lustleigh . . . and along the drainage lines in which the Torquay reservoir and Beadon Brook intake are situated " (*loc. cit.*, p. 66). Such disintegration along lines or belts has resulted in preferential weathering of the

[1] The Memoir describes Sheet 339 of the 1-inch geological map (New Series), which includes in its north-west corner a small area of the Dartmoor granite.

broken rock along those lines. Much of the ground along the course of the faults in the reservoir area is now submerged.

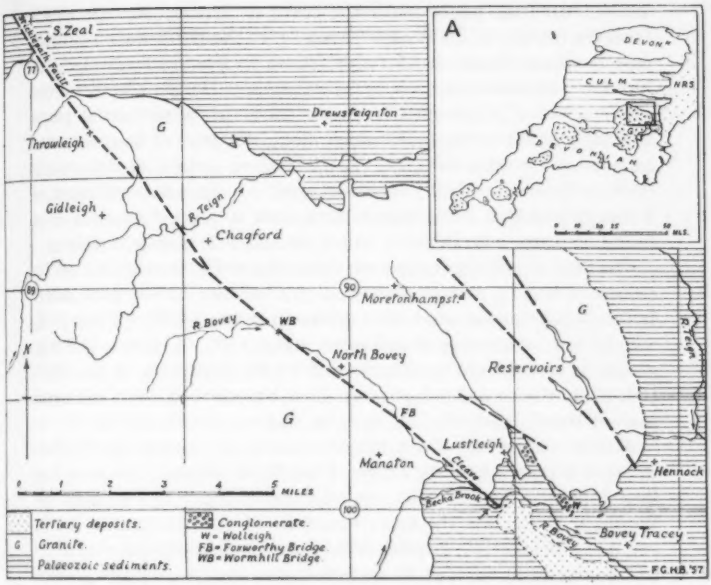
The line separating the north-eastern tract (as defined above) from the main Dartmoor area is a major fault, or fault-zone, which crosses the margin of the Dartmoor granite near Lustleigh and displaces it by a distance of at least a mile (Text-fig. 1). The margin is shifted to the south-east on the north-east side of the fault. The course of the fault can be traced north-westwards through the granite for 8 or 9 miles. And it is likely that it continues as a fault-zone still further to the north-west, to link up with the Sticklepath Fault, which displaces the northern margin of the granite near Okehampton as described by W. R. Dearman (1950). The name Lustleigh Fault is proposed for the south-eastern part of the Lustleigh–Sticklepath line of dislocation. Another fault lies nearly parallel to it, between 1½ and 2 miles away to the north-east, for part of its course, and other fractures with a similar trend are probably present in the area between Lustleigh and the reservoir fault-valleys already mentioned.

Evidence of Faulting in the Granite Area

The trends of faults within the granite area were established from field evidence of several kinds:—

(i) Displacement of the granite margin where it is broken by faulting;
(ii) The presence of zones or belts of broken rock, along which the granite is locally disintegrated into a crumbly, incoherent mass;
(iii) Topographical hollows, often arising from (ii), sometimes running in straight lines over considerable distances and occupied by streams;
(iv) Lines of springs;
(v) Boulder trains at the foot of fault-line scarps;
(vi) Dominant joint trends in the granite which lie parallel to faults;
(vii) The relative displacement of structures within the granite, such as minor intrusive bodies, runs of tourmalinization, etc.

Instances of most of these criteria appear in the following description. With regard to spring flow, the average rainfall on north-east Dartmoor is a little over 40 inches per annum; though there is a considerable run-off from the surface, much of the rainfall is temporarily held in peaty areas on the moor or in the soil of cultivated areas. A part of this water finds its way down along joints in the granite and appears as springs in favourable situations, as where the rock has been much fractured.



TEXT-FIG. 1.—Map of part of north-east Dartmoor, reduced from the 6-inch scale, to show main faults. Unshaded area, granite; horizontal ruling, Palaeozoic sediments; dots, Tertiary deposits. Faults shown by heavy broken lines. Six-inch sheet numbers are given in circles at the intersection of grid lines. Granite boundary in the north after Dearman (1950) and Osman (1924); near Lustleigh, revised by the author. Inset (*A*) shows area of map relative to Devon–Cornwall peninsula.

THE LUSTLEIGH FAULT

The margin of the intrusive granite against hornfelsed sediments (Culm) can be traced southwards from Lustleigh to the north bank of the River Bovey, where it flows in its steep-sided valley below Gradner Rocks. On the opposite bank of the river, however, near the point where the Becka Brook enters, hornfelsed sediments dip 40° north-north-east and are traversed by vertical joints having a north-westerly strike. The granite boundary cannot be located on this south bank until about a mile upstream of its position on the north side; thence it runs south-west towards Becka Falls. The fault producing this large displacement of the granite margin lies along the valley of the Bovey here. South-east of the right-angled bend where the river turns nearly north between Rudge Wood and Pullabrook

Wood,[1] the fault passes under the cover of Tertiary deposits which form the margin of the Bovey " basin "; to the north-west it courses past the steep slopes of Lustleigh Cleave to Foxworthy Bridge and Neadon. Granite tors such as Sharpitor and Harton Chest, on the upper slopes of Lustleigh Cleave, are traversed by prominent joints striking parallel to the fault, which along this part of its course has an average direction of 132°. The joints are vertical or dip steeply south. Sheared granite is seen in a pit ¼ mile west-north-west of Foxworthy Bridge. Lustleigh Cleave itself is a good example of a fault-line scarp, with its lower slopes littered with granite boulders.

The fault crosses the Langstone Cross–Barne Cross road at a saddle (700 ft. contour), and continues along a marshy hollow past Aller. It then passes to the south-west of North Bovey by New Corn Mill, maintaining an average direction of about 130°. Sheared, crumbly granite is seen in the road cutting 50 to 60 yards west of the Mill. It is likely that a north-north-west fault branches off from the main fault at North Bovey and occupies the hollow past Blackaller.

A little beyond New Corn Mill the main fault enters a marshy flat, where it is rejoined by the course of the River Bovey. The fault-line then follows a broad valley with its waterlogged alluvial plain to Wormhill Bridge (on the main Tavistock–Moretonhampstead road), and on to Batworthy. Exposures here are few, but old quarries 80 to 100 yards south-west of Wormhill Bridge reveal crumbly granite traversed by reddened zones and vertical shears striking between 125° and 132° (i.e. parallel to the course of the fault).

From Batworthy towards Chagford, the ground along the line of the fault rises to 900 feet O.D. at the saddle south-east of Nattadon Common. A good viewpoint from which much of the fault-hollow can be seen, looking south-east towards Lustleigh Cleave, is situated near here on the hillside ⅛ mile north-north-east of Higher Stiniel (6-inch sheet 90 south-west). The fault crosses the Chagford road at the right-angled bend just north of " The Quarries " (a house ½ mile south of Chagford church), its course being marked by several springs, and continues to the north-west by Padley Common. The old quarries 200 yards north-west of the right-angled bend in the road expose severely sheared and crumbly granite, with small felsite veins, and mark the effect of the faulting on the rock at that locality.

Between Padley Common (near Chagford) and Throwleigh the faulting appears to be expressed by a series of nearly parallel fractures *en echelon*, rather than by a single dislocation. These strike mainly between north-west and north-north-west, but the complex of smaller faults is more difficult to trace on the ground. The first of the *en*

[1] These and other place-names are taken from the 6-inch maps, shown by a grid on Text-fig. 1.

echelon fractures runs from Padley Common to the Gas Works (west of Chagford) and beyond. Another crosses the ridge of Waye Down, about a mile north-east of Gidleigh and just west of the old quarry marked on the 6-inch map (sheet 89 north-east). A mile beyond this point, to the south-east of Throwleigh, a marshy hollow marks the line of a fault, which continues north-west past Throwleigh church, along the valley towards South Zeal and Sticklepath. This is the Sticklepath Fault, as named by Dearman (1950), who showed that the northern boundary of the Dartmoor granite is displaced by it for a distance of $\frac{4}{5}$ mile (Text-fig. 1).

The direction of displacement of the Sticklepath Fault (north side moved to the south-east, relative to the south side) is the same as for the Lustleigh Fault, and the amounts are closely comparable. The evidence suggests a right-handed tear or transcurrent movement on the fault system; or alternatively, the net displacement may be a combination of vertical and horizontal movements. The orientation of the *en echelon* fractures between Chagford and Throwleigh, mentioned above, supports the idea of a right-handed tear-movement: they may be interpreted as a group of Riedel type fractures in a belt of shearing (see Blyth, 1949, p. 413 and fig. 10).

Possible Continuation of the Fault-system

When the Lustleigh–Sticklepath fault system is viewed in relation to a wider area it is evident that its continuation to the south-east, where it passes under the Oligocene deposits of the Bovey " basin ", would lie parallel to the long axis of that structure. Clement Reid (1913, p. 104) regarded the Bovey " basin " as a rift-valley, along which subsidence had taken place, thus allowing the accumulation of hundreds of feet of clays and lignites. Clays of this group seen in pits immediately east of the Devonian rocks of Knowle Hill, Newton Abbot, have steep easterly dips and probably mark the effect of a fault passing near to Knowle Hill on its north-east side. Such a fault would be aligned very closely with the Lustleigh fault.

A further prolongation of the line of fault to the south-east would cross the coast near Torquay. In this connection it is interesting to note that Austen (1842, p. 488) recorded that near Tor Abbey Sands " beds of new red sandstone were thrown into a vertical position ", and he ascribed this (and other effects seen in the neighbourhood) to a line of dislocation trending north-west. A continuation of the Sticklepath fault-line to the north-west would follow part of the valley of the River Okement, near Jacobstowe, and then would continue along a depression occupied by other Tertiary deposits (similar to those of Bovey) near Petrockstowe, 10 miles north-north-west of Okehampton. This possibility was noted by Wooldridge (1954, p. 237),

who also pointed out that faulting of similar trend is conspicuous in East Cornwall. Evans (1925) also remarked on the numerous north-west and south-east faults which traverse the Devon–Cornwall peninsula, and thought that they were "long posterior to the Hercynian folding".

There is evidence, therefore, for an extensive system of related north-westerly fractures over a wider area; in the north-east part of the Dartmoor granite they certainly form a major part of the fault pattern.

The age of the faults is less easy to determine. Some movement must have occurred in Tertiary times, since Oligocene clays near Bovey Tracey are affected, and it is possible that the faulting is entirely of Tertiary age. The fractures, however, may have been initiated much earlier, in the closing stages of the Armorican orogeny but following the intrusion of the Dartmoor granite. The later movements in Tertiary times would then be posthumous, affecting the younger sediments as well as the rocks of the Palaeozoic basement. Further work is still necessary to elucidate fully the history of the faulting.

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Notes on the Petrology and Mineralogy of the Barrovian Metamorphic Zones

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Abstract

The antipathetic relation between chloritoid and biotite in the lower metamorphic grades of the Barrovian zones and the genesis of the index minerals in the higher metamorphic grades are briefly discussed. The observed mineral assemblages of 13 new analyses of peltic schists are compared with the assemblage required by the mineralogical phase rule; good agreement exists provided allowance is made for magnesia acting as a separate component. Six new biotite analyses covering all of the Barrovian zones show an increase in the degree of replacement of Si**** by Al*** with increase in metamorphic grade. The ratio of FeO : MgO varies according to the associated ferromagnesian minerals and shows no regular relation to metamorphic grade.

Introduction

SINCE Barrow first demonstrated the possibility of mapping zones of progressive metamorphism in pelitic schists on the basis of changes in mineralogical assemblages the technique has been applied to metamorphic terraines in many parts of the world. Despite this little attempt has been made to study systematically the chemistry and mineralogy of these rocks. Several years ago the writer commenced a re-examination of the classical area first described by Barrow and, although the investigation is incomplete, it is considered desirable to publish some of the data so far obtained.

Petrography

Most of the material examined was collected from the classical area of Glen Esk, and from the coastal section between Stonehaven and Aberdeen. The pelitic schists from these areas have been described by Barrow (1893 and 1898), Harker (1939) and Williamson (1953); however, certain aspects of the petrology deserve additional comment.

In the biotite and garnet zones a feature of interest is that chloritoid and biotite seem to be incompatible under conditions of equilibrium. This is well seen in the coastal section north of Stonehaven (Williamson, 1953) where chloritoid schists within the biotite zone are composed of chloritoid, muscovite, chlorite, albitic plagioclase and quartz. In considering this incompatibility it is necessary first to consider the genesis of biotite. Tilley (1924) suggested that biotite arises from reaction between muscovite, antigoritic chlorite and iron ores with the concomitant formation of an amesitic chlorite; Barth (1952, p. 337) gives the following simplified equation for the reaction:

$$(1)\quad \underset{\text{Antigorite}}{5Mg_3Si_2O_5(OH)_4} + \underset{\text{muscovite}}{3KAl_3Si_3O_{10}(OH)_2} = \underset{\text{biotite}}{3KMg_3AlSi_3O_{10}(OH)_2} + \underset{\text{amesite}}{3Mg_2Al_2SiO_5(OH)_4} + \underset{\text{quartz}}{7SiO_2} + \underset{\text{water}}{4H_2O}$$

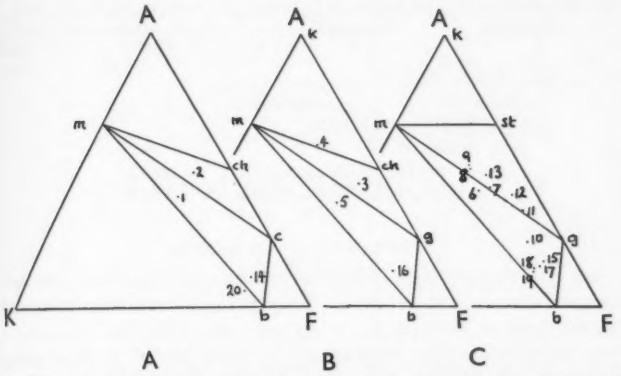
Thus, within the biotite zone, muscovite, biotite and an amesitic chlorite will form a stable association. In more aluminous rocks chloritoid appears and is usually associated with muscovite and chlorite but not biotite; equation 1 suggests that this chlorite, which is able to occur in stable association with muscovite under the physical conditions of the biotite zone, would be amesitic. The possible mineral assemblages are shown in the A.K.F. diagram (Text-fig. 1A) which differs somewhat from the equilibrium assemblages proposed by Turner (1948, p. 95). The assemblage muscovite-biotite-amesite is usually assumed to give rise to muscovite-biotite-almandine in the higher metamorphic zones; since it seems that the amesitic chlorite has a higher MgO : FeO ratio than the normal almandine garnet of garnet mica schists (Tilley, 1926), it would appear that the genesis of almandine also involves the formation of phlogopitic biotite, the reaction possibly being represented by equation 2.

$$(2)\quad \underset{\text{Amesitic chlorite}}{\left\{\begin{matrix}3Fe_3Mg_2Al_2Si_3O_{10}(OH)_8\\ Fe_2Mg_4Si_4O_{10}(OH)_8\end{matrix}\right.} + \underset{\text{muscovite}}{K_2Al_6Si_6O_{20}(OH)_4} + \underset{\text{quartz}}{2SiO_2} = \underset{\text{5 almandine garnets}}{Fe_{11}Mg_4Al_{10}(SiO_4)_{15}} + \underset{\text{phlogopite}}{K_2Mg_6Al_2Si_6O_{20}(OH)_4} + \underset{\text{water}}{16H_2O}$$

However, biotite is absent from the chloritoid schists within the garnet zone in the Stonehaven coastal section, the usual assemblage being chloritoid, muscovite, chlorite and garnet with albitic plagioclase and quartz. Since chloritoid and almandine garnet would be unable to hold all the magnesia in the rock the presence of a phase able to absorb magnesia is necessary but the occurrence of primary chlorite associated with muscovite in the garnet zone is very unusual. Possibly these rocks do not represent an equilibrium assemblage.

Though a considerable number of thin sections were made and examined it has not been possible to add much to what is already known about the genesis of the index minerals of the higher zones. Williamson (1953) has described the development of staurolite in chloritoid schists in the Stonehaven coastal section but it has not been possible to trace such a transition further inland, though this may only be due to lack of exposures. Within the kyanite zone the index mineral occasionally occurs as porphyroblasts crowded with inclusions of magnetite and minute garnets; Hietanen (1956, p. 19) suggests that this may indicate that kyanite has formed from the breakdown of staurolite as was originally suggested by Harker (1939, p. 226). Normally, however, kyanite and staurolite occur in the same rock and

there are no indications of the instability of staurolite. Sillimanite usually occurs replacing biotite but in one slide, cut from a specimen collected from the eastern slopes of Cairn Caidloch, Glen Esk, it can also be seen replacing kyanite. Although sillimanite normally arises from biotite (Tozer, 1955), this example and recent observations of



TEXT-FIG. 1.—A.K.F. diagrams showing plots of analysed schists and biotites (Tables I and II). A = greenschist facies, muscovite-biotite subfacies ; B = albite-epidote amphibolite facies, chloritoid-almandine subfacies ; C = amphibolite facies, staurolite-kyanite subfacies. m = muscovite, b = biotite, c = chlorite (amesitic), ch = chloritoid, g = almandine garnet, st = staurolite, k = kyanite.

Hietanen (1956) leave little doubt that it can arise by replacement of the other aluminium silicates, though such replacements are undoubtedly rare. There is no indication that muscovite decomposes to give potash feldspar and sillimanite.

CHEMISTRY

New analyses of pelitic schists from the Barrovian zones are given in Table I and are plotted on the appropriate A.K.F. diagram in Text-fig. 1. With the exception of a staurolite schist from Holnhead, Glen Esk, all the analyses plot within their correct mineralogical field with biotite occurring as an additional phase in the staurolite, kyanite and sillimanite schists due to the limited degree of substitution of iron by magnesium in almandine and staurolite. The analyses of the two muscovite-biotite schists do not plot on the join between theoretical muscovite and biotite but are very close to the join between theoretical muscovite and the plot of the analysed biotites. The Holnhead staurolite schist plots outside its appropriate field on the A.K.F. diagram and falls within the garnet, muscovite, biotite field. Equation 3

indicates how staurolite may develop in a chemical medium which, according to the A.K.F. diagram, is unfavourable. Since garnet and staurolite schists usually contain abundant excess silica in the form of quartz it would appear that the reaction is controlled by the availability of water.

(3) $x\underset{\text{Almandine}}{Fe_2Al_2(SiO_4)_3} + y\underset{\text{muscovite}}{K_2Al_4(Al_2Si_6O_{20})(OH)_4} + \left\{\begin{matrix} nK_2Fe_6(Al_2Si_6O_{20})(OH)_4 \\ nK_2Mg_6(Al_2Si_6O_{20})(OH)_4 \end{matrix}\right.$ biotite $+ 12H_2O$ water

$= 12\underset{\text{Staurolite}}{FeAl_4Si_2O_{10}(OH)_2} + (x-14)\underset{\text{almandine}}{Fe_3Al_2(SiO_4)_3}$

$+ (y-5)\underset{\text{muscovite}}{K_2Al_4(Al_2Si_6O_{20})(OH)_4}$

$\left\{\begin{matrix} n+5K_2Fe_6(Al_2Si_6O_{20})(OH)_4 \\ nK_2Mg_6(Al_2Si_6O_{20})(OH)_4 \end{matrix}\right.$ biotite $+ \underset{\text{quartz}}{18SiO_2}$

Mineralogy of the Biotites

Six biotites have been separated from the various zones, and their analyses are given in Table II. Their formulae have been calculated on the basis of 24(O,OH,F) to the unit cell—$(OH,F)_4X_2Y_6(Z_8O_{20})$—and phosphorus, when determined, has been placed in the Z group (Goldschmidt, 1954, p. 456). They show a marked similarity in composition and are characterized in particular by high alumina and low titania. Comparison with the analyses of biotites from igneous rocks (Nockolds, 1947) shows that the sum FeO + MgO + MnO is high

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Table I.—Explanation

(1) Muscovite-biotite schist, biotite zone, Skatie Shore, Stonehaven coastal section. Anal., Avery and Anderson, Melbourne.
(2) Chloritoid schist, biotite zone, Perthumie Bay, Stonehaven coastal section. Anal., Avery and Anderson, Melbourne.
(3) Chloritoid schist, garnet zone, Limpet Burn, Stonehaven coastal section.
(4) Chloritoid-staurolite schist, transition between garnet and staurolite zones, Limpet Burn, Stonehaven coastal section.
(5) Garnetiferous-muscovite-biotite schist, garnet zone, West Water, Glen Esk, Angus. Anal., Avery and Anderson, Melbourne.
(6) Muscovite-biotite schist, staurolite zone, Perthumie Bay, Stonehaven coastal section. Anal., Avery and Anderson, Melbourne.
(7) Staurolite mica schist, staurolite zone, Perthumie Bay, Stonehaven coastal section.
(8) Staurolite-garnet-mica schist, staurolite zone, West Water, Glen Esk, Angus. Anal., Avery and Anderson, Melbourne.
(9) Staurolite-garnet-mica schist, staurolite zone, Craig of Weston, Glen Esk, Angus.
(10) Staurolite-garnet-mica schist, staurolite zone, Hohnhead, Glen Esk, Angus.
(11) Staurolite-garnet-mica schist, staurolite zone, Craig of Cornescorn, Glen Esk, Angus.
(12) Kyanite-garnet-mica schist, kyanite zone, Bulg, Glen Esk, Angus.
(13) Garnet-sillimanite-mica schist, sillimanite zone, Craig of Dalhastnie, Glen Esk, Angus. Anal., Avery and Anderson, Melbourne.
Analyses by the writer unless stated otherwise.

TABLE I.—ANALYSES OF PELITIC SCHISTS FROM THE METAMORPHIC ZONES OF THE SOUTHERN HIGHLANDS OF SCOTLAND

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
SiO_2	53·84	59·10	54·30	45·97	46·29	48·60	62·17	47·49	43·36	58·53	50·46	50·39	60·27
TiO_2	1·54	0·93	1·03	0·97	1·58	1·82	0·55	1·78	1·43	2·53	2·16	0·18	1·07
Al_2O_3	20·28	22·58	23·96	33·29	23·11	23·06	20·71	26·59	33·25	18·55	23·92	26·82	18·78
Fe_2O_3	3·43	0·97	3·50	1·37	2·23	3·05	3·79	2·49	1·50	4·20	4·05	7·52	0·72
FeO	6·00	4·40	5·27	3·10	9·50	6·60	2·92	6·11	4·99	4·41	6·82	2·37	6·95
MnO	0·10	0·09	0·04	0·05	0·20	0·06	tr	0·12	0·03	0·05	0·09	0·14	0·15
MgO	3·25	1·82	1·43	1·12	3·92	3·46	1·24	2·53	2·07	2·24	2·61	2·00	2·52
CaO	0·74	0·81	0·20	0·81	1·38	1·57	0·90	2·16	0·84	0·97	1·77	1·80	2·38
K_2O	6·20	3·74	3·20	5·78	6·19	4·94	3·85	4·40	5·68	3·20	2·76	2·84	2·74
Na_2O	0·84	1·12	2·59	1·39	1·74	2·38	1·23	2·98	1·94	2·43	2·45	3·22	1·46
H_2O^+	2·68	3·63	4·16	5·40	2·95	3·46	2·79	2·43	4·53	2·50	2·70	2·77	2·39
H_2O^-	0·18	0·16	0·13	0·19	0·13	0·21	0·19	0·08	tr	0·17	0·06		0·12
P_2O_5	0·28	0·17	0·01	0·06	0·45	0·77	0·02	0·68	tr	nd	tr	nd	0·28
CO_2	0·60	0·65	nd	0·59	0·06	0·03	nd	0·07	nd	nd	nd	nd	0·08
	99·96	100·17	99·82	100·09	99·73	100·01	100·36	99·91	99·62	99·78	99·85	100·05	99·91
NIGGLI VALUES.													
si	122·7	239·6	192·0	149·0	128·0	143·7	260·1	137·6	126·0	226·0	152·0	150·0	223·9
al	40·0	54·0	50·0	63·0	37·5	40·1	50·8	45·4	57·2	40·2	42·8	47·4	41·1
fm	41·4	28·7	32·7	18·5	42·9	38·5	29·9	31·3	24·2	38·9	38·8	32·1	37·5
c	2·6	3·4	0·9	2·7	4·2	5·2	4·0	6·8	2·5	4·1	5·9	5·8	9·6
alk	15·9	13·9	16·2	15·8	15·4	16·2	15·3	16·5	16·1	16·8	12·6	14·8	11·8
mg	0·39	0·38	0·23	0·36	0·38	0·40	0·26	0·35	0·37	0·33	0·31	0·28	0·37
k	0·84	0·68	0·45	0·77	0·71	0·57	0·67	0·49	0·44	0·47	0·43	0·36	0·55

and fairly constant. It is of interest to note that the medium and high-grade biotites have a higher alumina content and lower silica content than the lower-grade biotite, suggesting that the degree of replacement of Si**** by Al*** in the Z group increases with increase in meta-

TABLE II.—EXPLANATION

(14) Biotite from muscovite-biotite schist, biotite zone, analysis of parent rock Table I, no. 1. Anal., Avery and Anderson, Melbourne.
(15) Biotite from muscovite-biotite schist, staurolite zone, analysis of parent rock Table I, no. 6. Anal., Avery and Anderson, Melbourne.
(16) Biotite from garnetiferous-mica schist, garnet zone, analysis of parent rock Table I, no. 5. Anal., N. J. Snelling.
(17) Biotite from staurolite-garnet-mica schist, staurolite zone, analysis of parent rock Table I, no. 8. Anal., N. J. Snelling.
(18) Biotite from staurolite-mica schist, staurolite zone, analysis of parent rock Table I, no. 7. Anal., N. J. Snelling.
(19) Biotite from garnet-sillimanite-mica schist, sillimanite zone, analysis of parent rock Table I, no. 13. Anal., N. J. Snelling.
(20) Low-grade biotite, Clove quadrangle, Dutchess County, N.Y. Anal., Ellestad. (Barth, 1936).
(21) Low-grade biotite from Nyuzyo, Iritono-mura, Japan. Associated with spessartine garnet. Anal., Miyashiro. (Miyashiro, 1953).
(22) Biotite from garnet-biotite gneiss, amphibolite or pyroxene hornfels facies, from Hattyulea, Samegawa-mura, Japan. Anal., Miyashiro. (Miyashiro, 1953).

TABLE II.—ANALYSES OF BIOTITES FROM PELITIC SCHISTS

		14.	15.	16.	17.	18.	19.	20.	21.	22.
SiO_2		36·62	33·49	34·15	34·06	35·85	35·03	36·82	35·88	36·01
TiO_2		1·98	1·73	1·75	1·42	1·73	2·56	4·82	0·35	2·74
Al_2O_3		17·56	19·92	20·08	20·52	20·60	20·38	16·34	18·52	18·65
Fe_2O_3		3·39	2·90	1·33	0·58	2·31	1·08	1·85	8·85	3·46
FeO		17·46	18·87	21·38	19·90	16·94	20·41	18·02	13·67	16·36
MnO		0·15	0·13	0·08	0·02	0·07	0·02	0·50	0·42	0·05
MgO		9·49	9·37	7·58	9·55	9·07	7·11	8·62	9·06	8·31
CaO		0·27	0·21	0·35	0·47	0·27	0·17	1·01	0·09	0·11
K_2O		7·50	6·10	8·65	7·57	8·06	8·62	8·82	6·24	8·57
Na_2O		0·48	0·40	0·59	0·41	0·71	0·96	0·47	0·82	0·97
H_2O^+		4·36	5·78	(3·94)	5·03	3·93	3·60	(2·73)	5·72	2·21
H_2O^-		0·10	0·25	0·12	0·21	nil	0·07	nd	0·72	1·89
F		0·20	0·49	nd	nd	nd	nd	nd	nd	nd
P_2O_5		0·19	0·15	nd	nd	nd	nd	nd	nd	nd
		99·75	99·79	100·00	99·74	99·54	100·01	100·00	100·35	99·33
Less O for F		0·08	0·21							
		99·67	99·58							
Cations :		24 (O, OH, F)								
z	Si	5·468	4·936	5·229	5·092	5·364	5·347	5·647	5·24	5·65
	P	0·024	0·019	—	—	—	—	—	—	—
	Al	2·508	3·046	2·771	2·908	2·636	2·653	2·353	2·76	2·35
y	Al	0·582	0·416	0·853	0·707	1·010	1·016	0·600	0·43	1·09
	Ti	0·222	0·192	0·201	0·160	0·195	0·294	0·556	0·04	0·32
	Fe***	0·381	0·322	0·153	0·065	0·260	0·124	0·214	0·97	0·41
	Fe**	2·180	2·327	2·737	2·487	2·119	2·605	2·310	1·67	2·14
	Mg	2·111	2·059	1·729	2·127	2·021	1·617	1·969	1·98	1·94
	Mn	0·019	0·016	0·010	0·003	0·009	0·003	0·065	0·05	0·01
x	Ca	0·043	0·033	0·057	0·072	0·043	0·028	0·166	0·01	0·02
	Na	0·139	0·114	0·175	0·119	0·206	0·284	0·154	0·23	0·30
	K	1·428	1·147	1·689	1·443	1·538	1·608	1·725	1·16	1·71
OH		4·341	5·684	4·023	5·013	3·920	3·664	2·791	5·51	2·31
F		0·094	0·229	—	—	—	—	—	—	—
X		1·610	1·295	1·920	1·634	1·787	1·920	2·045	1·40	2·03
Y		5·294	5·331	5·683	5·549	5·614	5·659	5·714	5·14	5·91
OH + F		4·435	5·913	4·023	5·013	3·920	3·664	2·791	5·51	2·31
mg		0·45	0·44	0·38	0·46	0·47	0·37	0·44	0·43	0·43
$\gamma = \beta^*$		1·626	1·641	1·643	1·638	1·638	1·640	1·625	1·660	1·641

* All ± 0·003.

morphic grade. A low-grade biotite from the Dutchess County metamorphics (Barth, 1936) is chemically similar to the Scottish low grade biotite but no suitable high-grade biotites from the Dutchess County area are available for comparison. The low- and medium-grade biotites from the Gosaisyo-Takanuki district, Japan (Miyashiro, 1953) do not show comparable silica and alumina variation though here the paragenesis is complicated by the high ferric iron content of the low-grade biotite and the presence of spessartine garnet in the low-grade schists of this area. It will be seen that there is an interesting correlation between the refractive indices of the biotites and the extent of substitution of Al*** for Si****.

There is no evidence from the available chemical data that the FeO : MgO ratio or the TiO_2 content of the biotites vary systematically with increase in metamorphic grade. Barth (1936) has discussed the FeO : MgO ratio in biotites from pelitic schists and has shown that this ratio will be affected by the nature of the other ferromagnesian minerals present. If the chemical and physical conditions are such that almandine and staurolite can form, these minerals will take up FeO in preference to MgO, leaving a biotite enriched in MgO, and the *mg* value of the biotite will be higher than that of the parent rock.

Table III gives the *mg* values of biotites from garnet and staurolite schists together with the *mg* values of their host rocks. The *mg* values of biotites from staurolite schists (Nos. 7 and 8) are considerably higher than those of their parent schists but there is little difference in the cases of biotites from garnet-mica schists (Nos. 5 and 13). For this to be so it is necessary for the garnets from these schists to have *mg* values very similar to those of the accompanying biotites; such values would indicate a pyrope content of the order of 30 per cent, rather high for garnets from mesometamorphic pelites.

TABLE III

Rock No.*	5	7	8	13
mg of biotite	0·40	0·47	0·46	0·37
mg of rock	0·38	0·26	0·35	0·37

* Corresponding to the rock numbers in Table I.

If cordierite is able to form, the preferential entry of magnesia into this mineral will result in the biotite being enriched in iron and ideally the *mg* value of the biotite will be lower than that of the parent rock. However, the presence of small amounts of magnetite or almandine in cordierite schists or hornfelses could well upset this distribution of iron and magnesia and this appears to have happened in one of the few cases where a biotite from a cordierite hornfels has been analysed together with the parent rock (Harker, 1954). In this instance, the *mg* value of the biotite is 0·55 and of the parent rock 0·53; these anomalous results are presumably due to the recorded presence of some

almandine. The effects of the presence of magnetite on the composition of biotite can be seen in the two biotite-muscovite schists from the Stonehaven coastal section. Mineralogically, these schists are composed of biotite, muscovite, quartz, plagioclase and magnetite; their analyses are very similar as are the analyses of the biotites but the *mg* values of the schists are lower than those of the biotites, a feature that can only be due to the crystallization of some of the iron as magnetite. The effect is comparable to that resulting from the presence of almandine and staurolite.

ACKNOWLEDGMENTS

The writer wishes to express his gratitude to Professor W. A. Deer, of the University of Manchester, for suggesting this topic for investigation and for his encouragement during the progress of the work; and to Professor J. C. Jaeger and Dr. G. A. Joplin, of the Australian National University, for their interest and assistance during the preparation of the work for publication. The cost of seven of the analyses quoted in this paper was defrayed by the Department of Geophysics of the Australian National University.

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Namurian Goniatites in the U.S.S.R.

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Abstract

Goniatite faunas characteristic of the principal Namurian stages are reported in many areas of the U.S.S.R. The faunas are listed, and a brief account of some recent systematic work is given.

In recent years a considerable amount of Russian research has been published on Carboniferous goniatites and their use in stratigraphy. Much of this is concerned with the Upper Carboniferous and Permian, but the present review is restricted to the Namurian as being of more interest to those working in Western Europe. It should be noted that in the Russian works to which reference is made the Lower Carboniferous extends upwards to include the Namurian, the Westphalian is referred to as Middle Carboniferous, and the Stephanian is called Upper Carboniferous. In this account the Lower Namurian includes beds up to the top of the Sabdenian Stage, and the Namurian beds above this are termed Upper Namurian. The faunas discussed come from several distinct areas in the U.S.S.R., which are treated separately in this account. I thank Dr. F. Hodson for encouraging me to prepare this review, and Mr. W. S. Bisat and Dr. C. J. Stubblefield for reading the manuscript.

1. Moscow Basin

Rocks of Namurian age are here largely cut out by unconformity (Shvetzov and others, 1937, p. 17) but the Tarussa Beds, at the base of the Serpukhovian Series contain *Cravenoceras*? (Librovitch, 1938, 1947, recorded as *Cravenoceras sp.* by Shvetzov and others, p. 16), and presumably are of *Eumorphoceras* Age.

2. Donetz Basin

The goniatites recorded from the Donetz Basin have been discussed by Librovitch (1946, 1947). The lowest Namurian formation, the Beshevo Limestone, contains *Cravenoceras beshevense* Librovitch, 1946 MS., which is stated by Librovitch (1938, p. 87) to be closely related to *C. malhamense* Bisat. Only indeterminate cephalopods are known from the Sabdenian Stage (*Homoceras* Age) in this area. Younger beds are recorded as containing *Reticuloceras* cf. *inconstans* (Phillips) and *Homoceras* cf. *striolatum* (Phillips) and at a slightly higher horizon *R. reticulatum* (Phillips) is recorded. The next highest

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goniatite horizon is that stated to contain *Gastrioceras cancellatum* Bisat, *G. martini* C. Schmidt, *G.* cf. *cumbriense* Bisat, *Branneroceras sp. nov.*, *Homoceratoides?* cf. *inostranzewi* (Karpinsky), *Schartymites?* and *Stenopronorites* of the *uralensis* group. Slightly above this horizon *Gastrioceras sp.* and *Reticuloceras* (*Bilinguites*) *superbilingue* Bisat and *R.* (*B*). aff. *superbilingue* are recorded, while the next horizon upwards also contains *R. superbilingue* together with *Homoceratoides divaricatus* (Hind), *Ht.? sp. nov.*, *Branneroceras branneri* (Smith), *Gastrioceras* cf. *marianum* (de Verneuil) *G.* aff. *karpinskii* Yanishevsky, *Anthracoceras sp. nov.* and *Schartymites barbotanus* (de Verneuil). Overlying this is a band with *Gastrioceras subcrenatum*, referred to the Middle Carboniferous and corresponding with the base of the Coal Measures in Britain.

3. Novaya Zemlya

A Namurian goniatite fauna from Novaya Zemlya was described by Librovitch (1938), and several other forms are listed in Librovitch (1947, pp. 58–9). The fossils apparently come from one general horizon of *Eumorphoceras* Age. The fauna described and figured in 1938 includes *Cravenoceras arcticum* Librovitch and a variety of that species, *C. cowlingense* Bisat, *C. petrenkoi* Librovitch, *Goniatites?* and *Stenopronorites uralensis* (Karpinsky). A new fauna listed in 1947 is stated to contain other MS. species of *Cravenoceras* (*C. septentrionale*, *C. inconstans*) and MS. varieties of *C. arcticum* and *C. petrenkoi*; also *Goniatites legatus* Librovitch MS., *Girtyoceras sp.*, *Berkhoceras boreale* Librovitch, 1938, gen. et sp. MS. (which is evidently closely similar to *Kazakhoceras* [*Neodimorphoceras*]), and *Proshumardites arcticus* Librovitch MS.

4. The Urals

(*a*) On the western slope of the middle part of the Ural Mountains the only Namurian goniatite fauna so far recorded (Librovitch, 1947, p. 59) is of *Eumorphoceras* Age and is said to contain several forms also found in Novaya Zemlya namely *Cravenoceras arcticum*, *C. arcticum* var. *berkhi* Librovitch MS., *C. arcticum* var. *multistriata* Librovitch MS., and *C. cowlingense* Bisat. This fauna is found in the upper part of the River Chusov.

(*b*) South-West Urals. The lowest Namurian fauna, which is probably of Sabdenian age, is found in a tributary of the River Sakmar, and contains *Uralopronorites mirus* Librovitch MS. Ruzhencev, 1949, *Metacanites sp.* and *Proshumardites?*.

A later goniatite fauna was first described by Krestovnikov (1935) but more recent collections (Librovitch, 1947) are stated to include *Reticuloceras eoreticulatum* Bisat, *R. reticulatum* var., *Homoceratoides*

divaricatus (Hind), *Ht. suranense* Librovitch MS., *Shartymites* cf. *barbotanus* (de Verneuil), *Gastrioceras ?*, *Bashkirites* cf. *discoidalis* Librovitch MS., *Proshumardites karpinskii* Rauzer-Chernousova and *Stenopronorites ferganensis* (Rauzer-Chernousova). An Upper Namurian fauna in this area includes *Reticuloceras* (*Bilinguites*) *bilingue* (Salter), *Homoceratoides* aff. *divaricatus* (Hind) and *Gastrioceras ?* and is evidently of Marsdenian age. At a still higher horizon *R. superbilingue*, *Gastrioceras cancellatum* Bisat, *G. martini* Schmidt [? = *G. crencellatum* Bisat], and *Schartymites* cf. *barbotanus* occur in another tributary of the River Sakmar.

(*c*) South Urals, Aktubinsk area. The lowest Namurian beds again contain *C.* cf. *arcticum* and *C.* aff. *cowlingense*. Sabdenian beds in the River Kii basin contain *Homoceras* aff. *beyrichianum*, *Girtyoceras ?*, *Uralopronorites mirus* Ruzhencev, 1949, *Metacanites quinquelobus* Kittl, *Pronorites* of the *P. cyclolobus* (Phillips) group, *Stenopronorites* cf. *uralense* (Karpinsky), *Proshumardites sp.* In the basin of the River Bakai there are Kinderscoutian beds with *Reticuloceras reticulatum*, *Schartymites barbotanus*, *Homoceras ?*, *Bashkirites discoidalis*, and *Proshumardites karpinskii*.

Ruzhencev (1947*b*) has described a new genus and species of Cheiloceratidae, *Irinoceras arcuatum* from this area but the horizon within the Namurian is unstated, and later (1949*b*) the prolecanitid genera *Rhipaeocanites librovitchi* Ruzhencev and *Dombarocanites chancharensis* Ruzhencev were described, the latter two in association with *Praedaraelites aktubensis* Ruzhencev. Ruzhencev (1956) has also described a new genus *Platygoniatites molaris* from the Lower Namurian of the region of the River Dombar.

(*d*) Eastern slopes of the Middle Urals. A lower Namurian bed with *Cravenoceras* aff. *richardsonianum* Girty and *Pseudonomismoceras ? sp. nov.*, and an Upper Namurian bed with *Gastrioceras marianum* (de Verneuil) are the only goniatites recorded by Librovitch (1947) in this area.

(*e*) South-East Urals. In the Schartymk area, goniatites from which have been described by de Verneuil (1845), Yanishevsky (1900) and listed by Librovitch (1939), a *Cravenoceras* fauna with *C. cowlingense* Bisat and *C. sp.* is again found in the Lower Namurian (Librovitch, 1939, 1947). Upper Namurian beds in this area contain (Librovitch, 1947) *Stenopronorites uralensis*, *Schartymites barbotanus*, *Verneuilites verneuili* Yanishevsky, *V. murchisoni* Librovitch, *Homoceratoides ? inostranzewi* (Karpinsky), *Ht. ? schartymense* Librovitch [*nom. nov.* 1947, p. 60, for the form described by de Verneuil (1845) under the name *Goniatites diadema* Goldfuss], *Gastrioceras marianum* (Verneuil), *G. karpinskii* Yanishevsky and *Dimorphoceras discrepans* (Brown). Ruzhencev (1949) has described a new genus and species *Megapro-*

norites sakmarensis from the "middle part" of the Namurian in this area.

Further to the south, in the Kizilo-Urtazimsk region, middle horizons of the Namurian contain *Proshumardites uralicus* Librovitch, *Uralopronorites mirus* Ruzhencev, 1949, *Metacanites* cf. *quinquelobus* Kittl, *Praedaraelites sp.*, *Gastrioceras? sp. nov.*, *Pseudohomoceras smithi* (Brown) Librovitch, 1947, gen. MS., and *Ps. latissimum* Librovitch gen. et sp. MS. Upper Namurian goniatites in this area include *Gastrioceras* cf. *karpinskii*, *Stenopronorites uralensis*, and *Proshumardites sp. G. cancellatum* Bisat is recorded (Librovitch, 1947), from the northern part of the Orsk region in beds of Yeadonian age.

Yanishevsky (1910), described a fauna from the Khabarn area including *Stenopronorites* cf. *uralensis* and "*Gastrioceras*" (*Verneuilites?*) *verneuili* Yanishevsky. New collections from this area have yielded forms closely resembling *Nuculoceras nuculum* Bisat (Librovitch, 1947).

In the eastern part of this area *Reticuloceras* cf. *inconstans* (Phillips), *Stenopronorites* cf. *uralensis*, *Gastrioceras* cf. *karpinskii*, *Bashkirites* cf. *discoidalis* and *Proshumardites* cf. *uralicus* are recorded (Librovitch, 1947, p. 61).

5. Central Asia

In the mountain ranges of Chatkalsk, Pskemsk, Uramsk, and Karzhantau a fauna of Upper *Eumorphoceras* Age is stated (Librovitch, 1947, p. 61) to contain *Eumorphoceras bisulcatum* mut. β H. Schmidt, *Cravenoceras* cf. *nititoides* Bisat [this species would now be referred to Hudson's genus *Cravenoceratoides*], *Homoceras* cf. *striolatum*, *Goniolobоceras sp. nov.*, *Stenopronorites ferganensis* and *Praedaraelites* aff. *praecursor* Fromaget. There is also a bed with *Homoceras beyrichianum* var. *biplex* Haug and var. aff. *coronatum* Haug, *Pseudohomoceras* cf. *smithi*, *P. ugamense* Librovitch MS., *Anthracoceras glabrum*, and *Syngastrioceras asiaticum* Librovitch MS. This is presumed to be of Sabdenian age. At a higher horizon *Reticuloceras reticulatum*, *Schartymites sp.*, and *Proshumardites sp.* occur; while still higher the Yeadonian stage is evidently represented by a bed with *G. cancellatum*, *A.* aff. *vanderbecki*, and *Glaphyrites* aff. *oblatus* Miller and Moore.

In the Fergan district and the Alaisk Mountains a Namurian fauna was first described by Rauzer-Chernousova (1928). Librovitch (1947), gives further details and states that a widespread Lower Namurian bed in this region contains *Cravenoceras alaicum* Librovitch MS., *C.* cf. *cowlingense*, *C.* aff. *richardsonianum*, *Eumorphoceras bisulcatum* Girty, and *Nomismoceras* aff. *vittiger* (Phillips). A Kinderscoutian fauna contains *R. reticulatum*, *Schartymites barbotanus*, *Nomismoceras*

(*Bashkirites?*) *dostalakum* Rauz., *Proshumardites karpinskii* Rauz. and *Stenopronorites ferganensis* Rauz. A Yeadonian fauna of *G.* cf. *cancellatum* and *Proshumardites sp.* is again present in this area.

Further to the west in the Nura-tau Mountains *Proshumardites* is present and in the central Tyan Shan area *Proshumardites keideli* (Leuchs), was described as long ago as 1919 (Leuchs, 1919).

In other parts of Central Asia *G. cumbriense* and *G.* cf. *martini* are recorded from the region of Son-Kul, *Cravenoceras* is recorded from the River Tekes and a characteristic succession with *Cravenoceras* (*Eumorphoceras* Age), *Proshumardites* (Kinderscoutian?) and *Gastrioceras* (Yeadonian) is found in the Pamir and Dapvaz regions. In Northern Kazakstan *Proshumardites* is known in the region in the south of the Semipalatinsk.

Systematic work.—It is unfortunate that many of the species and even genera mentioned in the above account have only MS. names, and that few of the records quoted are substantiated by figures of specimens. Nevertheless it is possible to give the following notes on several goniatite families, which summarize much of the recent systematic work.

Pronoritidae.—Ruzhencev (1949*a*), has given a complete and well-illustrated account of this family as found in the U.S.S.R. The only Namurian genera are *Megapronorites* Ruzhencev (type species *M. sakmarensis* Ruzhencev), in which there are five lateral lobes on the flank ; *Uralopronorites* (type species *U. mirus* Librovitch), which has six lateral lobes on the flank, the most ventral of which is very wide ; and *Stenopronorites* Schindewolf also with six lateral lobes on the flank. *Uralopronorites* is attributed to Librovitch (1947, p. 59), but was first figured by Ruzhencev (1949*a*).

Dimorphoceratidae.—This family was discussed and revised by Ruzhencev (1947*a*), and a short review is repeated in Ruzhencev (1950). The Viséan species *Goniatites looneyi* Phillips, 1836, is made the type species of the genus *Paradimorphoceras*. *Kazakhoceras* is erected to include species formerly considered to belong to *Neodimorphoceras* H. Schmidt (the type species of which is the Permian *Dimorphoceras texanum* Smith) but differing from that genus in having a carinate rather than a grooved venter. *Kazakhoceras* includes the well-known West European species *Neodimorphoceras hawkinsi* E. W. J. Moore and *N. scaliger* H. Schmidt. *Berkhoceras* Librovitch (1938), is a *nomen nudum*, but is stated to be close to *Neodimorhpoceras* [s.l.].

Also relevant for British workers is the erection of the genus *Politoceras* by Librovitch (1946, p. 80), the type species being *Goniatites politus* Shumard, 1858 = *Homoceratoides jacksoni* Bisat, 1930, a species well known in the Coal Measures. It is on features of both

ornament and sutures (the characters of the second lateral lobe) that this genus is considered necessary.

Eumorphoceratidae.—This family was erected by Ruzhencev (1940), and includes the Namurian genera *Eumorphoceras*, *Homoceras*, and *Reticuloceras*—or the bulk of the Namurian goniatites found in Britain. A discussion on this family is given in Ruzhencev (1950), but its relationship to and distinction from the Gastrioceratidae seem to be insufficiently stated and require clarification.

Librovitch (1946, p. 79), proposed the name *Bilinguites* as a subgenus of *Reticuloceras*, the type species being *R. superbilingue* Bisat. This subgenus includes *R. gracile* Bisat, *R. bilingue* (Salter), and *R. metabilingue* Wright and is thus characteristic of rocks of Upper *Reticuloceras* Age. It does not appear to the writer that there is any advantage in this procedure.

The generic name *Pseudohomoceras* Librovitch (1947, p. 60), the type species of which is the well-known British species *Goniatites smithi* Brown, 1841, is apparently a *nomen nudum* since it does not conform with Article 25, c (1) of the Rules of Zoological Nomenclature in that the characters of the genus are not given. If the genus were valid it would separate the coarsely ornamented, thicker shelled species of *Homoceras* from the more finely ornamented thinner shelled forms remaining in *Homoceras*, and might well serve a useful purpose.

Bashkirites Librovitch (1947, p. 60, type species *B. discoidalis* Librovitch) which is unfigured, is said to resemble *Nomismoceras ornatum* Foord and Crick in shape and ornament, but the suture line resembles that of *Goniolobоceras*. The relationship of this genus to *Hudsonoceras* E. W. J. Moore, 1946, will require investigation.

Conclusions

It is evident from the summary given by Librovitch (1947), that the principal stages of the Namurian, based on the work of Bisat and Schmidt in Western Europe, can be recognized by their goniatite fauna in almost every area discussed.

It may be added that in most areas the Namurian rocks rest on beds reported as containing a goniatite fauna of Upper *Posidonia* Age including *Paragoniatites* Librovitch, 1938. Also that in the Donetz Basin the Namurian is followed upwards by a faunal succession reminiscent of that found in Western Europe and including *Gastrioceras subcrenatum*, *G. listeri*, *Anthracoceras aegiranum* and *Politoceras politum*.

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GEOLOGICAL SURVEY AND MUSEUM,
LONDON, S.W. 7.

The Fuller's Earth of Whatley, Somerset

By P. C. Sylvester-Bradley and Frank Hodson, with an Appendix on the Ammonite Fauna by W. J. Arkell

Abstract

The Fuller's Earth Clay of the Whatley district nowhere rests directly on the Palaeozoic rocks, but is always underlain by Inferior Oolite. The Fuller's Earth Rock of the district contains two distinctive and successive faunas, the upper of which bears a suite of ammonites hitherto unknown from rocks of this age. It is correlated with the *Wattonensis* Beds of the Dorset Fuller's Earth.

Introduction

THE Fuller's Earth of the Whatley district has long been known for the richness of its brachiopod fauna (Davidson, 1851; Muir-Wood, 1936; McKerrow, 1953). In this area the Series is attenuated in comparison with its development elsewhere, a feature which seems to be the result of both the thinning of some members and the complete absence of others. It was mapped by the Geological Survey for the first edition of the one inch to the mile Sheet 19, of which a revised edition was published in 1873. On this map the Lower Fuller's Earth Clay is shown in places in the Whatley area resting directly on the Palaeozoic rocks and this has been taken as evidence for dating the final submergence of the Mendip archipelago below the Jurassic seas as having been accomplished only in Bathonian times. In one place on the map, the Lower Fuller's Earth Clay is shown as overlapped by the Fuller's Earth Rock on to the Inferior Oolite but over the greatest part of the relevant parts of the map the Inferior Oolite is shown intervening between the Palaeozoic floor and the Lower Fuller's Earth Clay.

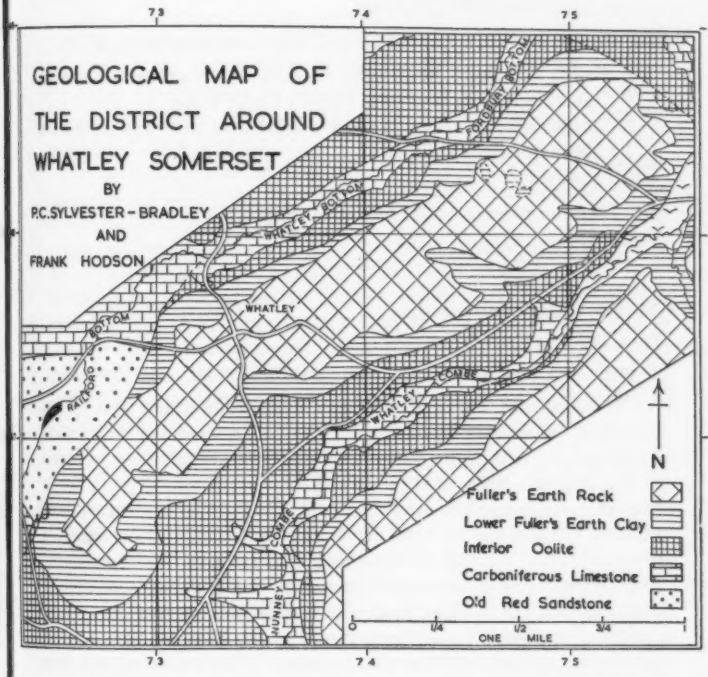
In this paper the evidence for the postulated overlap of the Bathonian strata on to the Palaeozoic floor is re-examined and refuted and a succession of faunal horizons within the Fuller's Earth is demonstrated.

History of the Present Investigation and Acknowledgments

The district was mapped by one of us (P.C.S.B.) in 1950. In 1953 a small fauna, including an ammonite, was collected by Mr. R. W. Girdler from material excavated in road widening operations in Whatley village. One of us (F.H.) visited the site from whence this collection was made but found the section already obscured. Fortunately a very large quantity of freshly excavated material was found laid out on a roadside some distance away which was said to be uncontaminated by materials from elsewhere. From these dumps a large fauna was

collected which included ammonites which were submitted to Dr. W. J. Arkell, who suggested they were of sufficient interest to warrant investigation into the stratigraphy of the beds which had yielded them. In consequence the area has been jointly re-surveyed by the authors.

Dr. H. M. Muir-Wood has named the brachiopods, Dr. L. R. Cox the gastropods and lamellibranchs, Dr. H. Dighton Thomas the corals,



and Dr. W. J. Arkell the ammonites. We are deeply grateful to all these specialists for their invaluable assistance and especially to the last, who has permitted his report to be appended to this paper. To Miss P. S. Walder for field transport and assistance in collecting and to the Research Boards of the Universities of Sheffield and Reading, for grants in aid of research, we are indebted.

Stratigraphy

The Fuller's Earth Rock of the Whatley area forms an outlier bounded on three sides by deep valleys which, in most places, cut down into

the Palaeozoic floor. The geological succession, with the estimated thicknesses of its component members, is as follows:

V. FULLER'S EARTH ROCK—about 20 feet present, consisting of:

2. *Rugitela* Beds, with an ammonite fauna dominated by *Procerites* spp. and with abundant *Ostrea matisconensis*.
1. *Ornithella* Beds, with ammonite fauna of *Tulites* and *Morrisiceras*. *Ornithella* absent at base.

IV. LOWER FULLER'S EARTH CLAY—10–20 feet, consisting of:

2. *Ostrea acuminata* Beds, with *Procerites*. *O. acuminata* extends up into base of overlying Fuller's Earth Rock.
1. Unfossiliferous clays [*Ostrea lotharingica* (*O. knorri* auctt.). Beds apparently absent].

Small non-sequence.

III. INFERIOR OOLITE—5–20 feet consisting of:

2. Flaggy oolites.
1. Oolitic freestone.

MAJOR UNCONFORMITY

II. CARBONIFEROUS LIMESTONE

I. OLD RED SANDSTONE

The succession within the Fuller's Earth is nowhere seen in unequivocal vertical superposition but can be demonstrated in the field by mapping. Although *Ostrea acuminata* is also doubtfully recorded in the *Rugitela* Beds, associated with *O. matisconensis*, the latter is overwhelmingly predominant there and does not occur in the Lower Fuller's Earth Clay, so that the *Ostrea* lumachelles make excellent marker bands. Such again is the case with some of the brachiopods. The *Ornithella* Beds are characterized by the abundance of species of that genus, to the virtual exclusion of *Rugitela*, whereas not a single specimen of *Ornithella* has been found in the *Rugitela* Beds. These vertically restricted faunas create distinctive mappable units and their distribution in the field bears out the reality of the succession given above.

THE INFERIOR OOLITE

The Inferior Oolite rests on the Palaeozoic with strong unconformity; the evenly planed, oyster-covered and mollusc-bored surface is a well-known feature of the district. In most places the junction of the Inferior Oolite and Palaeozoic is of this nature but along Railford Bottom the Fuller's Earth Rock is faulted against the Palaeozoic; the fault has been mineralized and contains barytes. It was precisely in this area that the first edition of the Geological Survey Sheet 19

showed Fuller's Earth resting unconformably on the Palaeozoic.[1] The tectonic juxtaposition of these two formations, revealed by our revision, removes the evidence upon which a delayed Bathonian submergence of the eastern Mendips was postulated.

Since this point is of some importance, examination was made into two other areas where the Geological Survey map showed Fuller's Earth resting directly on the Palaeozoics. One of these is at the head of Vallis Vale where, again, faulting seems to be responsible for Fuller's Earth being in contact with the Carboniferous Limestone. The absence of Inferior Oolite shown on the map east of East Cranmore is disproved by a section at the entrance to a disused quarry in which the Inferior Oolite can be observed resting on the mollusc-bored surface of the Carboniferous Limestone.

We claim, therefore, that all the evidence is consistent with the entire eastern end of the Mendips having been submerged before the end of Bajocian times.

The Inferior Oolite varies in thickness, these variations being possibly due to undulations on the Palaeozoic floor. Within the district covered by this paper, the best section is to be seen in a small disused quarry some 500 yds. E.S.E. of Whatley Church (737472), where 8 feet of massive oolitic freestones are overlain by 4 feet of flaggy oolites; these beds must lie very close to the top of the formation, since the succeeding Lower Fuller's Earth Clay is seen in the field immediately to the north.

Lower Fuller's Earth Clay

The Lower Fuller's Earth Clay is nowhere well exposed. We have seen no trace of the basal beds which form such a notable feature of the well-known section at Brambleditch Quarry, Doulting, some 6 miles to the W.S.W., which are characterized by a profusion of *Ostrea lotharingica*. Wherever the basal parts of the clay have been seen in the Whatley area they have proved unfossiliferous and no trace of the oyster has been seen in ploughed fields overlying the outcrop of the basal clays. It seems likely therefore that there is a slight non-sequence there. Minor breaks within the Inferior Oolite of the district have previously been recorded (Richardson, 1907, p. 398) and recognized by oyster-covered surfaces and bored beds.

Above the unfossiliferous clays, the *Ostrea acuminata* lumachelle is found with its maximum development as usual just below the lithological change from clay to amorphous rubbly limestone which marks the base of the Fuller's Earth Rock. The range of the oyster

[1] On the revised edition of the map, Inferior Oolite is shown intervening between the Fuller's Earth and the Palaeozoic.

straddles this junction, being found in the very lowest part of the Fuller's Earth Rock. In the lowest levels of the *O. acuminata* lumachelle, fragments of ammonites were found *in situ* in a newly dug ditch N.W. of Red Barn Farm (746483). These are *Procerites* spp. and include *P.* cf. *imitator* (Buckman). Loose ammonites found about 50 yds. N.W. of the Inferior Oolite quarry (737472) mentioned above, including *Procerites* sp. indet. and *Parkinsonia subgaleata*, are presumed to have been derived from this bed. *Procerites* sp. indet. was also found at a near-by site (733473).

Fuller's Earth Rock

The *O. acuminata* lumachelle is succeeded by rubbly limestones into which the oyster persists and is accompanied by a typical Fuller's Earth molluscan fauna with corals which seem commoner at this level than elsewhere. *Ornithella* is not recorded from these basal Fuller's Earth Rock beds but they are included with the *Ornithella* Beds on the map since the junction of rock and clay forms a convenient mapping boundary. The succeeding few feet of Fuller's Earth Rock are characterized by the abundant occurrence of species of *Ornithella*. These beds are certainly thin and when McKerrow (1953), claims that the loose ornithellids which he collected from this area came from so limited a thickness of rock that they may be regarded as a community, we would support the evidence upon which he bases his claim. Excellent exposures were revealed during ditching operations N.W. of Red Barn Farm (747483) and the outcrop can be picked up by means of the characteristic brachiopods which are strewn abundantly over it in ploughed fields. Such fossils as are presumed to have been derived from the *Ornithella* Beds are listed on p. 319 (column 2).

The *Ornithella* Beds appear to be succeeded by alternating beds of clay and rubbly limestone in which the most common fossil is *Ostrea matisconensis* accompanied by abundant *Rugitela* spp. These beds are called the *Rugitela* Beds in this account. They are extremely fossiliferous (see list, p. 319, col. 3). It is notable that not a single specimen of *Ornithella* has been found at this level, although thousands of brachiopods have passed through our hands. *Acanthothiris* is a conspicuous member of the fauna and the only specimens of *Dictyothyris* found in this area come from these beds. A large ammonite fauna has been collected from excavated *Rugitela* Beds. Many of these specimens are internal moulds encrusted with serpulae and oysters but we do not consider that this necessarily indicates that they are derived. These ammonites form the subject of an appendix to this paper by Dr. W. J. Arkell. If the Tulitidae of the "true" Fuller's Earth Rock (our *Ornithella* Beds) are regarded as an exotic element intercalated within the Bathonian, then it would appear that

at least a number of the species identified by him are what might have been expected in this newly discovered cephalopod-bearing stratum lying midway between previously known Lower and Upper Bathonian faunas, in that it includes (*a*) survivors from the lower beds, (*b*) first appearances of species characteristic of higher beds, and (*c*) elements proper to this intermediate level. It must be expected that new faunas discovered between those previously known will enlarge the range of such species whose vertical restriction is only apparent and controlled by the incompleteness of the palaeontological record.

All these ammonites were found in material which had been excavated from a road-widening south of Whatley church (735475), and in view of the fact that they were not found *in situ* it is necessary to state the reasons for believing them to have come from the *Rugitela* Beds. These are:

(i) The cutting was 7 or 8 feet deep and the workmen declared that the excavated materials were laid on bare grass verges on the roadside, where they can now be seen. To make quite certain that the dumped material could not have become contaminated from some other source, Mr. W. H. C. Widdicombe, District Surveyor at Frome for the Somerset County Council, was approached, and reports as follows: "I have diligently inquired into this matter and can confirm that all the soil, etc., deposited on the roadside verge at this particular spot W.S.W. of Whatley was excavated from the corner at Whatley. I cannot trace that material from any other source has been dumped there. In any event, if other material was dumped there in the past and of which I have no knowledge, it would have grassed over and become thoroughly consolidated and therefore the possibility of any fossils being picked up from that source does not appear to me to be at all likely." The underlying rocks at the dumping site belong to the Old Red Sandstone.

(ii) In this material no specimens of *Ornithella* were found; this indicates that the cutting did not penetrate the *Ornithella* Beds. Although *O. matisconensis* was extremely abundant, very few specimens of *O. acuminata* were seen, pointing again to uncontaminated material.

(iii) In the graveyard, a few yards north of the road cutting, the *Rugitela* Beds were exposed and yielded a characteristic fauna, which, however, did not include ammonites. This fauna was collected from a shallow excavation, not as deep as the road cutting, and induces us to think that the ammonite bed lay at the base of the cutting and was thin.

(iv) *O. matisconensis* was seen adherent to internal moulds of *Procerites*, which convinces us that such specimens at least are from the *Rugitela* Beds. The adherence of oysters and serpulae to the internal moulds of ammonites is not uncommon and Arkell has pointed out

LIST OF FOSSILS FROM THE FULLER'S EARTH OF THE WHATLEY DISTRICT
Column 1 = *O. acuminata* Beds; 2 = *Ornithella* Beds; 3 = *Rugitela* Beds
Foraminifera, bryozoa, and ostracoda, although present, have not been studied.

	1	2	3
ECHINOIDEA—			
Diplopodia cf. *pentagona* McCoy			x
Clypeus sp.			x
Holectypus depressus (Leske)		x	x
Pygorhytis ovalis (Leske)			x
Pygurus michelini Cotteau			x
Nucleolites sp.			x
VERMES—			
Serpula sp.	x	x	x
ANTHOZOA—			
Montlivaltia sp.		x	
CEPHALOPODA—			
Belemnopsis bessina (d'Orb.)			x
Oecotraustes serrigerus Waagen			x
Oppelia (*Oxycerites*) sp. indet. cf. *intermedia* Roemer			x
Parkinsonia (*Parkinsonia*) aff. *pachypleura* Buckman			x
Parkinsonia (*Gonolkites*) cf. *convergens* (Buckman)			x
Parkinsonia (*Gonolkites*) *subgaleata* (Buckman)	x		
Choffatia subbakeriae (d'Orb.)			x
C. homoeomorpha (Buckman)			x
Choffatia sp.			x
? *Wagnericeras* sp.			x
Procerites imitator (Buckman)			x
P. cf. *imitator* (Buckman)	x		
P. cf. *quercinus* (Terquem & Jourdy)	x		x
P. cf. or aff. *fullonicus* (Buckman)			x
P. cf. or aff. *tmetolobus* Buckman			x
Procerites sp. nov.			x
Procerites sp.	x		x
Cadomites or *Polyplectites* (nucleus)			x
Tulites cadus Buckman		x	
Lycetticeras comma (Buckman)		x	
Morrisiceras sphaera Buckman		x	
GASTROPODA—			
Pleurotomaria textilis Deslongchamps			x
Pleurotomaria sp.			x
Amberleya sp.			x
LAMELLIBRANCHIATA—			
Ostrea (*Liostrea*) *acuminata* J. Sow.	x	x	?
O. (*Catinula*) *matisconensis* (Lissajous)		?	x
Modiolus anatinus W. Smith			x
M. (*Isoperna*) *plicatus* J. Sow.			x
Meleagrinella sp		x	x
Isognomon (*Mytiloperna*) *bathonicus* M. & L.			x
Entolium corneolum (Young and Bird)			x
Camptonectes laminatus (J. Sow.)			x
Chlamys (*Radulopecten*) *vagans* (J. de C. Sow.)			x
Plagiostoma ovalis (J. Sow.)			x
Limatula cerealis Arkell			x
Ctenostreon sp.			x
Lopha marshii (J. Sow.)			x
L. costata (J. de C. Sow.)	x		

	1	2	3
LAMELLIBRANCHIATA—			
Trigonia elongata (J. de C. Sow.) var. *lata* Lycett			x
Opis cf. *trigonalis*			x
Anisocardia minima (J. Sow.)			x
A. fullonica Cox			x
A. bathensis Cox			x
Anisocardia sp.		x	
Pseudotrapezium cordiforme (Deshayes)		x	x
Quenstedtia rodburgensis (Lycett)			x
Protocardia buckmani (Morris & Lycett)			x
Pleuromya alduini (Brongiart)			x
P. calceiformis (Phillips)		x	x
P. uniformis (J. Sow.)		x	x
P. subelongata (d'Orb.)		x	x
Ceratomya concentrica (J. de C. Sow.)		x	x
C. striata (J. Sow.)			x
Gresslya peregrina (Phillips)			x
Pholadomya deltoidea (J. Sow.)			x
P. lirata (J. Sow.)		x	x
P. ovalis (J. Sow.)			x
P. moschi Rollier			x
Goniomya literata (J. Sow.)		x	x
G. intersectans (W. Smith)			x
Thracia depressa (J. de C. Sow.)			x
BRACHIOPODA—			
Rhynchonelloidella smithi (Dav.)		x	x
R. smithi crassa Muir-Wood			x
R. wattonensis Muir-Wood		x	x
R. globosa Muir-Wood		x	
R. mesoloba Muir-Wood			x
Kallirhynchia platiloba Muir-Wood			x
Dictyothyris subreticulata (Douville)			x
Ancanthothiris powerstockensis Buckman & Walker			x
Rugitela bullata (J. de C. Sow.)		x	x
R. powerstockensis Muir-Wood			x
R. emarginata (J. de C. Sow.)			x
Ornithella bathonica bathiensis (Rollier)		x	
O. brutonensis Muir-Wood		x	
O. cinctaeformis Muir-Wood		x	
O. pupa Muir-Wood		x	
Tubithyris globata (J. de C. Sow.)		x	x
T. whatleyensis (Buckman)			x
Wattonithyris fullonica Muir-Wood		x	x
W. pseudomaxillata Muir-Wood		x	x
W. nunneyensis (Buckman)			x
W. wattonensis Muir-Wood			x
W. midfordensis Muir-Wood			x
W. parva Muir-Wood			x
" *Terebratula* " *pseudoglobata* Muir-Wood		x	

that there is no need to invoke the derivation of such specimens by erosion of earlier beds.

(v) One specimen (6903) was found at the site of the cutting at the base of a fencing post and had clearly come from the excavated beds.

Thus the sum total of all the evidence points to the whole of the dumped material having been excavated from 7 or 8 feet of beds and no extraneous material having been incorporated. Also there is no reason to think that any or all of the ammonites were derived fossils, particularly since some of the species were only previously recorded from higher levels and are almost as surprising as those which were formerly known only from lower beds.

The *Rugitela* Beds were also seen in material thrown out from a ditch N.W. of Red Barn Farm (747483).

Comparison with other Areas

In the district south of Sherborne, Kellaway and Wilson (1941) have demonstrated that above the " true " Fuller's Earth Rock and separated from it by some 30 feet of clay there occurs a second rock band which they named the *Wattonensis* Beds. There is a considerable difference in the fauna of the two rock bands, that of the *Wattonensis* Beds being characterized by the absence of *Ornithella* and the greater abundance of *Rugitela* (Kellaway and Wilson, 1941, p. 160). The more characteristic and abundant species may be listed as follows: *Wattonithyris wattonensis, W. nunneyensis, W. whatleyensis, W. fullonica, Tubithyris whatleyensis, T. powerstockensis, Rugitela bullata, R. cadomensis, R. powerstockensis, Rhynchonelloidella wattonensis, R. smithi, Acanthothiris powerstockensis, Trigonia elongata, Nucula waltoni, Ostrea matisconensis, Amberleya fowleri.*

The Fullers' Earth Rock of the same district wedges out to the south, but is maintained northwards as a continuous band as far as Bath. North of Bath it exhibits great lateral changes recently described by Arkell and Donovan (1952). In the Sherborne district it carries a fauna dominated by species of *Ornithella* and accompanied by ammonites of which those belonging to the Tulitidae are notable. These brachiopod beds become even more fossiliferous towards the north. At the Maperton road-cutting (Richardson, 1909, p. 123; Muir-Wood, 1936, p. 24), the most abundant fossils are *Ornithella bathonica, O. brutonensis, O. cinctaeformis, O. pupa, Rugitela bullata, R. cadomensis, Wattonithyris fullonica, W. nunneyensis, W. wattonensis, Rhynchonelloidella smithi, Pholadomya* spp.

Apart from the species of *Ornithella*, the brachiopods listed are also found in the *Wattonensis* Beds, but the abundance of *Ornithella* in the Maperton road-cutting Beds contrasts so strongly with their complete absence in the *Wattonensis* Beds, that the two faunas have a completely different aspect. Also, notable absentees from the Maperton road-cutting beds are *Acanthothiris powerstockensis* and especially *Ostrea matisconensis.*

It will be seen, therefore, that the faunal characters which distinguish the *Wattonensis* Beds from the " true " Fuller's Earth Rock of the Sherborne district are precisely those which distinguish the *Rugitela* Beds from the *Ornithella* Beds of the Whatley outlier. It would seem that the two rock bands of the Sherborne district are represented within the thickness of the Fuller's Earth Rock of Whatley, where they are not separated by a thick clay as at Sherborne. A study of the faunal lists drawn up in the past from places in the eastern Mendips such as Whatley and Nunney shows that, in fact, mixed assemblages derived from both beds have been compounded.

Although we agree that McKerrow (1953), collected *Ornithella* spp. derived from a relatively thin bed and that his deductions concerning palaeo-ecology based thereon are not invalidated by his specimens covering a considerable range of time, yet we cannot concur that his records of the ratio of *Ornithella* spp. to *Rugitela* spp. have any significance. His collecting sites were large ploughed fields, two of which seem to straddle the boundary between the *Ornithella* Beds and the *Rugitela* Beds and our experience convinces us that in such areas the composition of faunas collected loose, from the surface of ploughed fields, fluctuates rapidly over small distances and that soil creep is one factor amongst others capable of mixing elements of two distinctive faunas.

The main part of the fauna collected is in the museum of the Department of Geology, Reading University. This collection contains all the ammonities but selections of the brachiopods have been deposited with the British Museum (Natural History) and the Geological Survey Museum, London.

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APPENDIX

Ammonites from the Fuller's Earth Rock, Whatley, Somerset

By W. J. ARKELL

The remarkable collection here reported on consists of some fifty-three more or less fragmentary ammonites collected from spoil of the road-cutting near Whatley church. All came from the *Rugitela* Beds, which appear to be the latest beds preserved on the outlier. From a lower horizon, the *Ornithella* Beds, or from a part of the rock slightly below the main *Ornithella* level but included for mapping purposes with the *Ornithella* Beds, I received from neighbouring outcrops three ammonites which can be identified positively as *Tulites cadus* Buckman, *Morrisiceras sphaera* Buckman and *Lycetticeras comma* (Buckman), all three characteristic of the *Subcontractus* Zone of the Middle Bathonian.

The main collection therefore comes from a level a few feet above the typical *Subcontractus* Zone fauna, which is common in the lower part of the Fuller's Earth Rock from south of Sherborne to north of Bath.

The list is as follows (Reading University Geological Department Museum registration numbers):—

Oecotraustes serrigerus Waagen, 6357, 6359.
Oppelia (*Oxycerites*) sp. indet., cf. *intermedia* Roemer, 6358.
Parkinsonia (*Parkinsonia*) aff. *pachypleura* Buckman, 6592.
,, (*Gonolkites*) cf. *convergens* (Buckman), 6593.
Choffatia subbakeriae (d' Orbigny), 6912.
,, *homoeomorpha* (Buckman), 6911, 6753.
,, sp. (large fragment), 6906.
,, sp. indet., fragments, 6591, 6910.
? *Wagnericeras* sp. or spp., fragments, indet., 6758, 6903.
Procerites imitator (Buckman), 6589, 6905, 6914, 6354.
,, ,, cf. *quercinus* (Terquem & Jourdy), 6759, 6350, 6351, 6352, 6353, 6360, 6361.
,, ,, cf. or aff. *fullonicus* (Buckman), 6752, 6756, 6590, 6349, 6355.
,, ,, cf. or aff. *tmetolobus* Buckman, 6913.
,, ,, spp., fragments, indet. (numerous).
Cadomites or *Polyplectites* sp. indet., nucleus, 6760.

This is an extraordinary mixture of Lower, Middle, and Upper Bathonian species. The predominant forms are the large *Procerites*,

which in England and France is a genus characteristic of the *Zigzag* Zone at the base of the Bathonian. Two of the species from Whatley can only be compared to *P. tmetolobus* and *P. fullonicus*, the types of which respectively came from the *Zigzag* Bed at Burton Bradstock and the base of the Lower Fuller's Earth Clay at Combe Hay railway-cutting, Somerset, where it was collected *in situ* by L. Richardson in a bed with *Ostrea lotharingica* (Richardson, 1910, p. 426).[1] It also occurs in the *Ostrea lotharingica* Beds at Doulting Bridge and Vandenesse, the Mâconnais, and Toul, Meurthe-et-Moselle (Caillasses à *Anabacia*), but it is not so far known from the *Zigzag* Bed of Dorset.

The two species of *Parkinsonia* also can only be compared to two common species of the *Zigzag* Zone of Dorset, where both abound in the *Zigzag* Bed on the coast and in the Crackment Limestones around Sherborne. Hitherto no *Parkinsonia* has ever been recorded from any higher beds in England, and I have not been able to discover any authentic occurence of *Parkinsonia* above the Lower Bathonian in any other country.

On the other hand, the Whatley collections contain no specimen of *Zigzagiceras*, *Morphoceras* or *Ebrayiceras*, which are equally characteristic of the Lower Bathonian in Dorset and France and many other parts of the world, nor any of the species of *Oecotraustes* common at that horizon in Dorset (Arkell, 1951–5, pp. 67–9, 132–141). The indeterminable *Cadomites* or *Polyplectites* nucleus could have come from any part of the Bathonian, though in England an early date would be more probable.

The Middle and Upper Bathonian are likewise represented at Whatley by accessory species, while the best-known guide fossils are again absent. There is no *Tulites*, *Morrisiceras*, or *Lycetticeras*, the zonal index genera of the Middle Bathonian, despite the abundance of these in the neighbouring outcrops and their occurrence even near Whatley, as stated above. The only species of the normal *Subcontractus* Zone found in the Whatley *Rugitela* Beds besides Perisphinctids, is *Oecotraustes serrigerus* Waagen (see Arkell, 1951–5, pp. 69–70).

Of the Middle and Upper Bathonian Perisphinctids, the commonest at Whatley is *Procerites* cf. *quercinus*, which is known from the *Wattonensis* Beds at West Cranmore, Somerset (P. C. Sylvester-Bradley coll), and Lake Farm, Thornford, Dorset (J. Fowler coll.), and also by some uncrushed fragments among the " sherds " just above the *Wattonensis* Beds at Langton Herring, Dorset (Arkell, 1940; new collection, 1954). Another common species at Whatley is *Procerites*

[1] Mr. Richardson writes (October, 1955) that he was very careful, when describing this section, to record only fossils collected *in situ*. No Fuller's Earth Rock was exposed in the cutting. In 1922 his specimen was made the type of " *Parkinsonites* " *fullonicus* by Buckman.

imitator (Buckman), the type of which came from the Hampen Marly Beds (probably Middle Bathonian) of Fritwell cutting, Oxfordshire (Arkell, 1951–5, p. 14). It has been found also in the Twinhoe Iron-shot near Wellow, Somerset (T. Fry coll., 1950, Bristol Univ. Museum), which is early Upper Bathonian (Arkell, 1951–5, pp. 11–12, 65).

The *Choffatiae* are, so far as they can be named, species characteristic of the Cornbrash, while one, *C. homoeomorpha*, has also been obtained from the Upper Fuller's Earth of Combe Hay mine, Midford. Previously neither species was known from below the Upper Bathonian, and no *Choffatia* has ever been found below the Middle Bathonian; nor has any *Wagnericeras*. On the other hand, the most characteristic Upper Bathonian ammonite genus, *Clydoniceras*, was not found at Whatley.

Summary

The assemblage from the *Rugitela* Beds at Whatley is highly anomalous. It does not contain any of the zonal index species or genera of the Lower, Middle, or Upper Bathonian (*Zigzagiceras*, *Morphoceras*, *Tulites*, *Morrisiceras*, *Clydoniceras*), but consists of a mixture of accessory ammonites individually considered characteristic of all three subdivisions of the Bathonian but never previously found together :—

Upper Bathonian	*Choffatia subbakeriae* „ *homoeomorpha*
Middle Bathonian	*Oecotraustes serrigerus* *Procerites imitator* „ cf. *quercinus*
Lower Bathonian	*Parkinsonia* aff. *pachypleura* „ cf. *convergens* *Procerites* cf. *fullonicus* „ cf. *tmetolobus*

Since this assemblage has been demonstrated to overlie " normal " Fuller's Earth Rock with *Tulites cadus*, *Morrisiceras sphaera* and *Lycetticeras comma*, its position must be presumed to be somewhere in the upper part of the Middle or lower part of the Upper Bathonian. Of these, the evidence of the ammonites is strongest for late-Middle Bathonian, and with this the evidence of the abundant brachiopods agrees, for they correlate with the *Wattonensis* Beds, or " Upper Fuller's Earth Rock ", of the Sherborne district, in which *Morrisiceras* lingers.

The occurrence of two species of *Choffatia* hitherto known only in the Upper Bathonian is no great surprise. On the other hand, if the bed is late-Middle Bathonian the occurrence of the two species of *Parkinsonia* and of the two Lower Bathonian *Procerites* is unique and presents a difficult problem. There is no evidence for derivation and the local stratigraphy is against it, since the basal beds of the Fuller's Earth, in which these ammonites would be expected (and in

which a specimen of *Parkinsonia subgaleata* (Buckman) was found near by—specimen 6594) are separated from the rock capping the hill at Whatley by about 10–20 feet of Lower Fuller's Earth Clay and *Ornithella* Beds, which confirms the old Survey map in this respect at least.

There remains the question of misidentification. It is true that the two fragments of *Parkinsonia* leave much to be desired, but they are unquestionably *Parkinsoniae* of two different subgenera, and that is a major anomaly, whatever their specific identity. The *Procerites* are more numerous, and here the difficulty is rather to be sure of the specific characters of the *Zigzag* Zone species to which they seem to be comparable, since both *P. fullonicus* and *P. tmetolobus* were founded on single incomplete specimens, showing only the middle whorls and neither inner whorls nor body chamber. However, after prolonged and repeated handling of the type specimens and all available comparative material I am forced to conclude that there is probably no tangible difference between them and their Whatley representatives, though it remains possible that if adequate material of all growth stages one day becomes available from both levels specific differences may be detected. This applies to the *Procerites* and the *Parkinsoniae*.

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A New Upper Carboniferous Echinoid from Texas

By PORTER M. KIER

ABSTRACT

A new echinoid species, *Eupholidocidaris belli*, is described from the Upper Carboniferous of Texas.

INTRODUCTION

DR. W. C. BELL has very kindly sent to me for study several specimens of a new species of *Eupholidocidaris* which he collected from the Upper Carboniferous of Texas. As Upper Carboniferous echinoids are extremely rare, Dr. Bell's find is a very significant one, and I am greatly indebted to him for the opportunity of examining these interesting specimens.

Family LEPIDOCENTRIDAE Loven

Genus *Eupholidocidaris* Kier, 1956, p. 15

Type species.—By original designation, *Eupholidocidaris brightoni* Kier.

Eupholidocidaris belli sp. nov. Text-fig. 1.

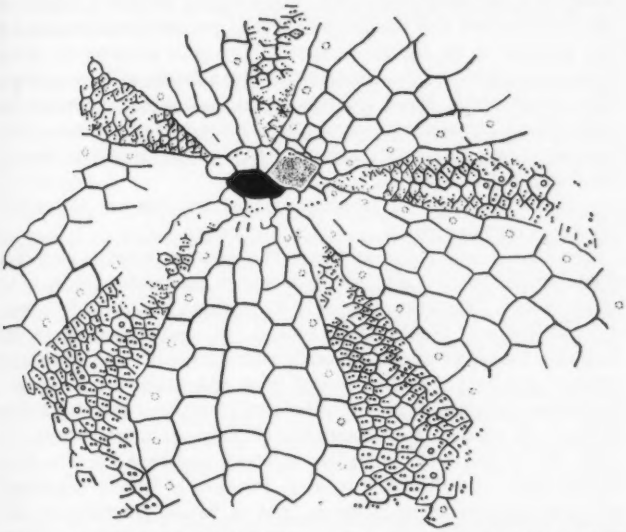
Diagnosis.—This species is characterized by five columns of interambulacral plates, and by the absence of tubercles on the median columns of the interambulacral plates.

Material.—There are eight specimens none of which is complete. All the specimens are flattened and badly weathered, and in none of them is the oral surface exposed. In two specimens most of the upper surface of the aboral side is visible; in two others most of the undersurface of the aboral surface is visible. In the holotype (UT 12089) the apical system is present, but in the other specimens the lantern has broken through the aboral plates destroying the apical system. In the other four specimens only part of one or two ambulacra and interambulacra are preserved. All the specimens are in the collections of the Department of Geology of the University of Texas.

Description.—Because of the flattening of the specimens, the original shape of the echinoid is unknown. In the largest specimen (UT 12090) the diameter at the midzone is 70 mm., the width of an interambulacrum 25 mm., and an ambulacrum 14 mm. In the smallest specimen (UT 12091) with a diameter of 45 mm., an interambulacrum is approximately 18 mm. wide and an ambulacrum is 8 mm. wide at the midzone.

Apical System.—Although the shape of the apical system has been distorted due to the shifting of plates during fossilization, the original plate arrangement of the system is apparent (Text-fig. 1). In the holotype, a specimen with a diameter at the midzone of approximately

45 mm., the apical system has an approximate diameter of 8 mm. All the oculars and genitals except genital 4 are present. Genital 2 is approximately twice the size of the other genitals and almost all of its surface is pierced with madreporic pores. The presence of madreporic pores is of particular interest for as noted by Jackson (1912, p. 172), their occurrence is unusual in Paleozoic echinoids. Genital 2 is pierced by only one genital pore. In genitals 3 and 5 there appear to be four



TEXT-FIG. 1.—*Eupholidocidaris belli* Kier. Drawing made on photograph of holotype. The tubercles on the adambulacral plates were removed during cleaning and their former position is indicated by a dotted circle. X 2.

genital pores with only three in genital 1. However, these pores are often difficult to distinguish and their number is therefore not certain. The oculars are smaller than the genitals and each is pierced by a single pore. All the oculars were probably originally insert but due to the distortion of the apical system, ocular two in the holotype has been isolated from the periproct by the shifting of its adjacent genitals.

Ambulacra.—There are six columns of ambulacral plates at the midzone of each ambulacrum, with approximately four plates equal to the height of an adambulacral plate. Midway between the apical system and the midzone, the ambulacral plates of the third and fourth columns are alternatingly much larger than the others and each bears a primary tubercle. These plates form a median column of larger

plates in each ambulacrum. Although, none of the specimens exhibit the oral side intact, it is evident by the large number of large, tubercle-bearing ambulacral plates which occur on some of the slabs that the ambulacra on the oral side were all composed of large plates. These plates are far larger than any occurring on the aboral side. All the ambulacral plates imbricate orally, and under the adambulacral plates.

Interambulacra.—At the midzone, there are five columns of thin plates in each interambulacrum. There appear to be five columns of plates in the first row immediately oral of the apical system, but it is not possible to be certain because of the poor preservation of the specimens. However, there certainly are five columns in the second row. The adambulacral plates are pentagonal, and of approximately the same size as the interambulacral plates of the median columns. They each bear one large primary tubercle. The plates of the median columns are hexagonal and bear no tubercles.

Lantern.—Portions of lanterns are present but are too poorly preserved for description.

Comparison with other species.—This species belongs with little doubt to the genus *Eupholidocidaris* and is the second species to be referred to it. The other species is *E. brightoni* Kier from the Lower Carboniferous at Hook Head, Ireland. *E. belli* is similar to this species in having six columns of tuberculated plates in each ambulacrum orally; in having a median row of large ambulacral plates aborally, and in having much larger oral ambulacral plates than aboral. Furthermore, both species have adambulacral plates of approximately the same size as plates of the median columns, and have the same plate imbrication. *E. belli* differs from *E. brightoni* in having five instead of eight interambulacral columns, and in having tubercles on only the adambulacral plates and not on the plates of the median columns. The presence of tubercles on just the adambulacral plates is a feature found also in *Pholidocidaris* Meek and Worthen and further illustrates the affinity of *Pholidocidaris* with *Eupholidocidaris* (Kier, 1956, p. 15).

Horizon.—Upper Carboniferous (Pennsylvanian)—Marble Falls Formation equivalent to the Lower Westphalian in Europe. Found 200–225 feet above the top of Barnett shale.

Locality.—East slope of Bluff Creek, about 2,500 feet above its mouth, south-west of Sloan Community, San Saba County, Texas.

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A note on the Pitchstones of Arran

By C. E. Tilley

Abstract

Biotite is recognized as the dominant mineral of the arborescent, plumose, and scopulitic growths found in the Arran pitchstones. The chemical composition of the pitchstone group of glasses is briefly discussed in terms of the experimental data on the hydrous granite system.

THE most detailed description of the groundmass constituents of the Arran pitchstones is recorded by Harker in the Geological Survey memoir on North Arran (1903, pp. 120–127), and his account has been supplemented by Tyrrell in the later Arran memoir (1928, pp. 229–236).

Tyrrell also presented in this later account more recent chemical analyses of the principal types of pitchstones he recognized. The three main elements in the groundmass which have been recorded are microlites, arborescent growths, and finer crystallites. They have been referred in the main to hornblende though clinopyroxene has also been recognized and figures prominently in the Glen Ashdale pitchstone (Scott, 1913).

In the course of a further examination of pitchstone sections it has become clear that clinopyroxene is a more frequent member of these assemblages than descriptions would suggest and that biotite (with its chlorite pseudomorphs), hitherto unrecorded, is a very common constituent.

The best known of the pitchstones—Corrygills—contains normally all three minerals which may be briefly noted as follows :

1. *Microlites.*—These occur as isolated rods or in radiate groups ; both augite and hornblende are the constituent minerals. Not infrequently pyroxene may form the core of a composite microlite with parallel outgrowths at its extremities of slender fibres of hornblende. Both minerals may be recognized in their characteristic cross sections.

2. *Arborescent growths.*—(*a*) The fir tree-like elements consist normally of a hornblende microlite acting as a trunk fringed with minute plates of biotite, yellow-brown to brown in pleochroism. These arborescent growths of biotite may be in part replaced by chlorite.

(*b*) The slender " laths " with plumose terminations known as scopulites are built of biotite. These may assume a more complex form as intersecting radially disposed " laths " each with its plumose terminations yielding a composite scopulite, in the form of a feathery circle with " laths " as diameters. Closer study shows that the chief elements of the scopulite are plates of biotite fringed at their edges by

fine diverging plates of the same mineral, the whole in cross section then appearing as the slender " lath " with its plumose termination. The composite scopulite consists of two or more intersecting biotite plates each with its plumose borders.

In the pitchstones these scopulites show varying stages of chloritization.

3. These larger elements of the groundmass are normally surrounded by a court of clear glass, but beyond this clear zone more minute crystallites may be disseminated through the glossy matrix. Many of these crystallites are seen to be biotite (or chlorite derived therefrom) revealed most conspicuously as birefringent cross sections of plates with parallel extinction.

Biotite in arborescent growths or as simple hexagonal plates of the type noted above are characteristic of representatives of the other chief

TABLE 1

	1	2	3	4	A	B
SiO_2	76·73	75·72	75·84	76·80	74·20	76·50
Al_2O_3	11·27	13·86	13·01	12·95	14·57	13·03
Fe_2O_3	1·00	0·70	0·82	1·02	0·09	0·35
FeO	1·07	0·29	0·69	nil	0·71	0·78
MnO	0·39	0·17	—	—	0·01	—
MgO	0·16	0·15	0·10	0·07	0·27	0·38
CaO	0·80	0·78	0·72	0·83	1·06	1·42
Na_2O	3·96	3·99	4·01	4·22	4·00	3·26
K_2O	4·40	4·30	4·12	4·10	5·13	4·42
TiO_2	0·17	—	0·19	0·19	0·27	0·07
Total	99·95	99·96	99·50	100·18	100·31	100·21
H_2O+	4·52	5·52 (total)	4·98	8·72	5·70	5·68

	Co-ordinates in the System Qz—Or—Ab		
	Qz	Or	Ab
1.	36·9	27·7	35·4
2.	36·7	27·1	36·2
3.	37·5	25·9	36·6
4.	36·7	25·8	37·5

1. Pitchstone (Corrygills type), Arran. (Tyrrell 1928, p. 234).
2. Pitchstone, Silver Cliff, Arizona. (Washington 1917, p. 122).
3. Pitchstone, Ampasibitika, Madagascar. (Washington 1917, p. 144).
4. " Rhyolite glass " (pitchstone), Marysvale, Utah. (Washington 1917, p. 124).
A. Artificial glass of granite of Stone Mt., Georgia, (900° C, 980 bars).
B. Obsidian, Mt. Kiamis, Java, (900° C, 980 bars). A and B, Goranson (1931, p. 496).

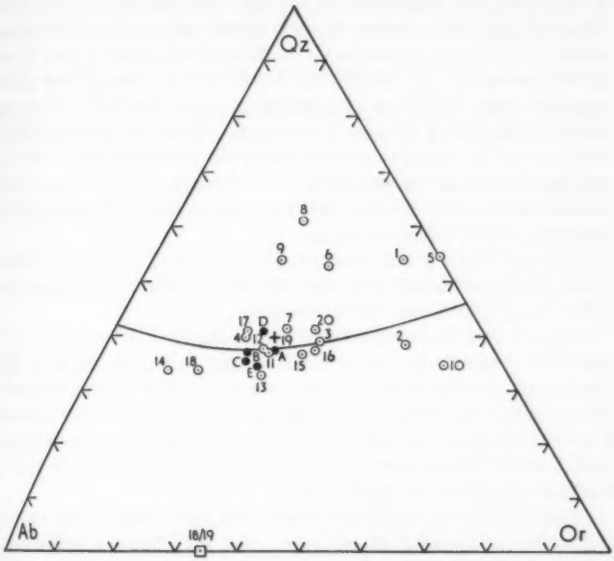
types of Arran pitchstones and also of the porphyritic pitchstones of the composite sill of Glencallum Bay, Bute.

The occurrence of biotite as incipient crystallizations in pitchstones with the water and potash content revealed in the analyses of these Arran rocks is scarcely a matter of surprise.

Dr. Tyrrell (*pers. comm.*) is of opinion that the pitchstones must have solidified under at least 5,000 feet of Triassic, Jurassic, and Cretaceous sediments followed by an unknown thickness of Tertiary basalts.

The experimental data of Goranson (1931) indicate that the solubility of water in granite magma at 900° C. and 980 bars water vapour pressure is 5·7 per cent (Table 1, Analyses A and B). At lower tem-

peratures near the ternary minimum of the system of Text-fig. 1, water solubility would be equivalent to 6·3 per cent. The figure of four to four and one-half per cent water shown by the Arran pitchstones could be an equilibrium amount in the magma at about 800° C. at a depth of about two kilometres (500 Kg/cm²) which is not an



TEXT-FIG. 1.—Plot of salic normative constituents (less anorthite and corundum) of analysed pitchstones in the system $NaAlSi_3O_8$–$K\,AlSi_3O_8$–SiO_2 at 1000 Kg/cm² water vapour pressure (Bowen and Tuttle 1952). The pitchstones of Arran represented in solid circles (A–E) A Corrygills, B Glen Shurig, C and D Tormore, E Cir Mhòr. A, B. C, E (Tyrrell, 1928, p. 234), D (Harris and Brindley, 1954, p. 820). 18, 19, 18/19, glassy contact facies, interior felsite and anorthoclase microphenocrysts of Jafnadal dyke (Hawkes and Harwood, 1932, p. 167). The pitchstones A (Corrygills), 11 (Silver Cliff, Arizona), and 12 (Ampasibitika, Madagascar) plot close to the ternary minimum in this system.

overestimate of the probable depth of cover at the time of their intrusion.

The compositions of five Arran pitchstones (A–E of Text-fig. 1) have been plotted in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2 at 1,000 Kg/cm² water vapour pressure.

With these are also plotted a number of other pitchstones mostly taken from Washington's Tables (1917).

The main group of the whole series is seen to cluster along the central portion of the quartz-feldspar boundary curve of the system, all the Arran pitchstones being so included.

The Corrygills pitchstone A falls close to the ternary minimum of the system and others of closely comparable composition are set out in Table 1 (analyses 2–4) where the analyses have been recalculated water free, with the water content of each set out separately. The thermal valley in this hydrous system (at 1,000 Kg/cm^2) runs parallel to the quartz boundary. At 500 Kg/cm^2 water vapour pressure the quartz boundary runs parallel to and somewhat above that indicated in the system of Text-fig. 1 (Bowen, 1954, p. 10). The main cluster of pitchstone points lie therefore clearly within the thermal valley. The remaining pitchstone analyses, however, include some which are clearly suspect, either as inferior analyses or as representative of a glassy phase subjected to later chemical change.

There is in fact a *prima facie* case for considering all the pitchstones which lie beyond the belt of the thermal valley as being unrepresentative of the liquid from which they congealed.

Nos. 8, 9, and 14 are reported as containing 12·3, 10·0, and 9·7 per cent water respectively, figures which suggest later acquisition of this constituent ; further Hawkes and Harwood (1932) have given adequate demonstration that glass 18 of the Jafnadal dyke of Iceland has suffered a marked change in composition. The remaining high potash pitchstone 2 with 7·45 per cent K_2O and only 1·60 per cent H_2O+ is a doubtful claiment as an original liquid.

Of the pitchstones within the cluster two show excess water (No. 4 of Text-fig. 1, Esterel 7·32 per cent ; No. 4 of Table 1, Marysvale, 8·72 per cent) ; whether these have acquired water at a later stage without other effective change in chemical composition cannot be inferred.

It would be of great interest to pursue inquiry into the status of water in pitchstones along the lines initiated by Ross and his collegues (1955) on obsidian and perlites.

This, however, is but one of many petrological problems of pitchstones that remain ; to their solution the continuing investigation of the classic Arran pitchstones in particular, promises contribution in rich measure.

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Accessory Brachial Structures in Long-looped Brachiopods

By Graham F. Elliott

Abstract

Accessory structures on the brachial loops of certain brachiopods are considered to be initiated as supplementary calcification, and when persisting to the adult stage, to become part of the loop.

THE long-looped terebratuloid brachiopods, both recent and fossil, show considerable variety between different genera in the form of the loop or brachial support. Particular patterns of loop, however, are found to be common to most genera in a family, whether they occur in immature or in adult shells: a convenient summary for the superfamily Terebratellacea (Mesozoic-Recent) is that of Elliott (1953). In addition there occur rarely certain minor loop-structures, not necessarily found in all individuals of the species displaying them, which do not appear to be malformations, or pathological in origin: these are briefly discussed below.

The development of the Recent *Dallinella obsoleta* (Dall), from the Pacific, was described by Beecher (1895). He figured an early growth-stage when the sole brachial support developed is a small median septum on the floor of the dorsal valve: this is common to all terebratellaceans, and is in the Dallinidae succeeded by the growth of the descending branches from the crura to the septum, and by the development of the pre-campagiform hood on the septum itself. In *Dallinella*, however, Beecher figured two small lateral expansions on the posterior edge of the septum, both in the very early septal growth-stage and in the pre-campagiform stage, and stated that these projections are not present in all specimens (*op. cit.*, pp. 393–4, pl. 3, figs. 3, 4, 8). Thomson (1927, p. 232) commented that their significance was obscure. In this recent species these accessory structures are not seen after the pre-campagiform stage.

Gemmarcula aurea is an English Lower Cretaceous species whose development was described by the writer (Elliott, 1947). The earliest internal growth-stage known is the pre-campagiform, when the septal hood, triangular in cross-section, shows lateral projections or flanges. These accessory structures survive throughout all subsequent growth-stages up to the adult terebrataliform stage, becoming gradually modified into auricular projections or "ears" projecting from the points where the ascending branches of the loop merge into the transverse band. Similar structures are seen in the development of the American *G. arizonensis* (Cooper, 1955).

Elliott (1947, p. 154) considered that if the adult accessory structures

were imagined as continuing to fuse with the median septum, the result would be a loop somewhat like that of the Cretaceous dallinid *Kingena*; this overlooks the fact that in the frenuliniform stage of *Gemmarcula*, when connecting bands exist between transverse band and septum, being thus comparable to the young adult *Kingena* (Elliott, 1952, figs. 1–5), the accessory structures are still distinct.

In *Gemmarcula* the accessory structures are present in all individuals as far as known.

Finally Ager (1957), reconstructing the adult loop from serial sections of *Zeilleria elliotti* from the English Lower Jurassic, described

TEXT-FIG. 1.—Reconstructed brachiopod to show secretion of accessory loop-structures, based on the dallinids *Gemmarcula* (Cretaceous) and *Dallinella* (Recent). A. Early growth-stage, × 16, showing brachial valve interior with schizolophous lophophore, early septum, and accessory projections; septum separately figured on right. B. Adult × 1, brachial valve interior showing plectolophous lophophore and dalliniform loop with accessory projections or "ears"; thin tissue invests the loop and joins it to the cirrated canals of the lophophore, and is indicated by conventional stippling. The loop is separately figured on the left.

and figured "wedge-like, ventrally-directed processes" projecting from left and right below the transverse band, apparently from the posterior portions of the ascending branches. These accessory structures do not occur in all individuals, and immature specimens are not known.

For evaluation of the significance of these structures, it is necessary to consider the fleshy lophophore of the brachiopod animal; the adult stage is conveniently dealt with first.

Examination of the plectolophous lophophore in a full-grown recent terebratellacean shows that the points of recurvature of the lophophore canals, where the side arms curve into the median coil, lie well posterior to the points of recurvature of the ascending loop-branches into the transverse band; ears or supplementary structures on these loop-corners would form slight additional support or stiffening in the lophophore tissues which envelop the loop.

The immature schizolophous lophophore in the early septal growth-stage consists of two curved arms which extend anteriorly and recurve so that the adjacent growing tips lie posteriorly against the septal

pillar. It is in this region of rapid growth, where curvature of the developing lophophore leads later to formation of the pre-campagiform hood, that the small lateral septal projections are secreted, as in *Dallinella*, and it is suggested that they come in a similar category to the calcareous loop-spines known in many dallinids. In this family secretion and resorption are heavier than in the comparable terebratellids, where loop-spines do not occur. When, as in *Gemmarcula*, the early accessory structure persists, it eventually becomes part of the loop and possibly functioned as suggested above. It would seem that such structures, when they survive to the adult stage, change their function in much the same fashion as the septum, which begins as part of the brachial support and often ends as a cardinalian buttress.

The presence of accessory structures in an adult zeilleriid is nteresting, for whilst these brachiopods show loop-spinosity like many dallinids, very little is known of their loop-development, and the exact relationship between the two families is still largely a matter for conjecture (Muir-Wood, 1955, Stehli, 1956, Elliott, *in press*); it remains to be seen whether dallinid and zeilleriid accessory structures have similar origins.

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The contact between Tertiary Granophyre and Torridonian Arkose on Minishal, Isle of Rhum

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(PLATE XI)

Abstract

Re-examination of the contact between granophyre and arkose on Minishal, Isle of Rhum, shows it to be a tectonic junction in which the effects of crushing and shearing have been largely obscured by contact alteration.

In a description of the acid rocks of Western Rhum, given by G. P. Black (1954), there is an account of a junction where Tertiary granophyre was found to pass into Torridonian arkose. Recently Sir Edward Bailey (1956) has discussed this junction whilst considering the faulted contact between granophyre and Torridonian sediments in the west of Rhum and he regards it as a continuation of the ring fault seen in the eastern part of the island (Bailey, 1945). Black's description of the field setting, and the petrography and chemistry of the transition rocks, are discussed by Bailey, who does not consider that these justify Black's conclusion that the acid rocks were formed from the arkose by metasomatic alteration *in situ*.

One of us has made the suggestion that the gradation from arkose to granophyre is due to melting and contact metamorphism of the two rocks by a later gabbro enveloping the peridotite mass (Hughes, 1955, p. iv). Bailey makes a similar suggestion with the heating attributed to the peridotites and also puts forward as an alternative the possibility that " at the time of the formation of the ring-fault, granophyre magma, rising inside and somewhat superheated, remained liquid until movement ceased " (Bailey, 1956, p. 423).

During the course of remapping parts of Rhum, the junction in question was re-examined, since the conclusions reached by Black were at variance with those arrived at by one of us (C. J. H.). From this re-examination it was found that the crush rocks, described by Black from the arkose-granophyre junction to the west of Minishal, continue eastwards until the granophyre and arkose terminate just to the east of the scarp on the eastern side of Minishal. Here they are separated from the peridotites by about 15 yards of ground that is free from exposures. This section has been revisited by two of us (W. J. W., C. H. E.) and Hughes' findings confirmed. The junction is about 2¾ miles W. 10° N. of Kinloch Castle and on the scarp mentioned above. (For a detailed description of the locality, see Black, 1954, p. 260.)

The mylonite along the junction of granophyre and arkose is clearly seen on the south side of Minishal about 100 yards to the west of the scarp. On approaching this junction from the north, the Torridonian

in the last 30 yards is seen to be very much disturbed and brecciated for a few yards from the mylonite zone. When traced eastwards the mylonite becomes less easy to distinguish from the arkose and granophyre. Also, the arkose is bleached and indurated until it assumes a felsitic appearance on the weathered surface and is not dissimilar to the granophyre, with the result that there is apparently complete gradation from arkose to granophyre. Close examination of the rocks in the transitional zone revealed some outcrops of a very fine-grained rock, which were seen to be traversed by dark bands and streaks similar to those in the mylonites to the west. These fine-grained rocks formed a nearly vertical zone which could be traced laterally into the mylonites. A suite of specimens was collected from outcrops ranging from undoubted granophyre to arkose (8763–8771).[1] On further examination of these and other specimens, the impression of shearing gained from the field outcrops was confirmed. On polished surfaces lines of shearing and brecciation were plainly visible (Plate XI, figs. 1 and 3) and in thin section mortar structure was seen (7919 and Plate XI, fig. 2). It is also evident from the thin sections that the shearing has not been the latest event at this junction; both granophyre and arkose show signs of considerable thermal alteration and unless sections of fairly large area are made it is not easy to discern the crushing because of the masking effect of the later thermal metamorphism.

This particular junction between arkose and granophyre cannot, therefore, be taken as showing transition from one to the other. It is a tectonic junction in which the effects of crushing and shearing have been largely obscured by contact alteration due to the later adjacent basic and ultrabasic rocks.

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[1] Numbers in brackets refer to specimens in the Accession Series collection of the Dept. of Geology and Mineralogy, Oxford.

FIG. 1.

FIG. 2.

FIG. 3.

CRUSHED GRANOPHYRE AND TORRIDONIAN ARKOSE, MINISHAL, ISLE OF RHUM.

EXPLANATION OF PLATE XI

FIG. 1.—No. 8768 Polished surface of crushed granophyre, natural size. The surface is seen to be crossed by a number of dark-coloured sub-parallel shear lines. The small light-coloured patches are due to the presence of fragments of uncrushed granophyre.

FIG. 2.—No. 8768 Photomicrograph of crushed granophyre. Crossed nicols, × 12. A fragment of granophyre is seen to be surrounded by finer grain material which has been derived from the comminution of granophyre. The brecciation has been accomplished in two stages with nearly complete shattering of the rock followed by later less intense shearing that was concentrated along definite lines. The latter phase is represented by the dark streaks seen in fig. 1 and the dark band seen in the upper left-hand side of this figure.

FIG. 3.—No. 8769 Polished surface of brecciated Torridonian arkose, × 3. The specimen was taken at a distance of 3 yards from the crushed granophyre, 8768. The brecciation is similar to that seen in the arkose close to the faulted junction with granophyre on the south of Minishal.

GENERAL NOTE. Both specimens come from the base of the scarp along the east side of Minishal.

REVIEW

JURASSIC GEOLOGY OF THE WORLD. By W. J. ARKELL. 1956. Oliver and Boyd, Edinburgh, pp. 806, 28 tables, 102 text-figures, 46 plates. Price £5 5*s*.

Given prominence in the author's preface, but not entirely clear from the title, is the fact that nearly all the evidence and conclusions of this book are drawn from marine strata with ammonites. It calls for no explanation or apology as this is a unique study on which much more may be built. The whole work far surpasses any previous attempt at world-wide description of strata in that Dr. Arkell has re-interpreted published figures of all the fossils concerned, although in many cases he has also himself collected, or studied collections. The publication (1957) of the complementary Ammonoid Section (Part L) of the *Treatise on Invertebrate Palaeontology* (ed. R. C. Moore) now makes possible a fuller use of the more detailed stratigraphical sections.

In 1933, Dr. Arkell quoted d'Orbigny as an inspired stratigrapher, but as one who had caused confusion by his premature classification. Now by 1956 he has reconstructed and used an amplified version of d'Orbigny's sequence of stages, as his considered scheme of subdivision of the Jurassic for the whole world; this he explains very concisely in his introductory chapter which may be considered a challenge to stratigraphers working on all other systems. He admits the partial failure of the upper (Tithonian) part of the scheme, but it seems that this may eventually illustrate the wisdom of waiting for opinion to develop in a now better-informed audience; the Purbeckian and Portlandian stages ought thus to be in considerable danger of relegation, if viewed from elsewhere than Britain.

The bold concession to international uniformity of including the British Callovian in the Middle Jurassic is very welcome, as it removes an unnecessary discrepancy. Criticism has already been expressed and answered (*Geol. Mag.*, xciii, pp. 436–8).

The long systematic section (575 pages) is arranged by continents, but with some flexibility for convenience. It is a pity only that the chapters on Western Europe (particularly parts of France) are so condensed in places into a detailed ammonite commentary; in these sections, presumably for general space economy, the author appears to have left an appreciable gap between his writing and the knowledge which a reasonably well-informed reader could be expected to have; the gap is of course covered by references. In other countries more space is given to far less detailed basic information.

There are numerous useful maps of outcrop distribution (seldom, however, with indication of underground extent of the beds), but very few palaeogeographic reconstructions. The author regards these as likely to lead to rigidity of thought with the particular instance in mind of the western part of the British Isles in the Mesozoic. As such speculation can more profitably be made at present by the author than by most of his readers, it seems a pity not to gamble slightly on the stimulant effects of a little such indulgence.

The marine faunal realms of Uhlig and others are re-defined and strengthened. There are several useful distribution maps including, for example, one of the Boreal Cardioceratidae; this however, would be improved by indication also on the map of what remained unaffected by the " spread " of these forms. On climate the author crisply attacks the general inability to drop the idea that poles " must have carried with them some glaciation ", when probably there was no glaciation at all at this and many other times. Summarizing the distribution of diastrophisim he is much concerned with propositions and laws by Stille and others, whereas the inconclusive nature of his evidence seems to suggest that no conclusions of this kind can be drawn at all. With regard, however, to the many supposedly distinct types of troughs and geosynclines, the author apparently sees continuous gradation with no definable pattern. In effect he plays on the suspicion that we are

still bound in our study of rocks of the crust by the involuntary contemplation of sea-level as it happens to be at any place to-day.

The whole work displays restraint on theoretical aspects of the subject, but this does not suggest timidity or confusion as the vast array of facts is excellently marshalled, being particularly well planned for easy reference ; the style of writing and the selection of illustrative photographs reveal great delicacy of touch which gives this most important work still further distinction.

N. F. H.

CORRESPONDENCE

CRATANIOPHYLLUM, A NEW NAME FOR A CARBONIFEROUS CORAL GENUS

SIR,—Lang, Smith, and Thomas [*Index of Palaeozoic Coral Genera*, Brit. Mus. (Nat. Hist.), 1940, p. 26] proposed the name *Barbouria* for *Craterophyllum* Barbour (*Publ. Nebraska Geol. Surv.*, iv, (3), 1911, p. 38), a junior synonym of *Craterophyllum* Foerste, 1909, and of *Craterophyllum* Tolmachev, 1931. Dr. Dorothy Hill has pointed out to us, however, that *Barbouria* is pre-occupied by *Barbouria* Rathbun [*Bull. Mus. comp. Zool. Harvard*, liv, (15), 1912, p. 455], for a crustacean. We now propose *Crataniophyllum* (*κρατάνιον, τό*, a kind of cup ; *φύλλον, τό*, a leaf) to replace *Craterophyllum* Barbour *nec* Rathbun *nec* Tolmachev, the type species being *C. verticillatum* Barbour (op. cit., p. 38, pls. 1–4), probably from the horizon of the Oread Limestone (Pennsylvanian), of Nehawka, Cass County, Nebraska, U.S.A.

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A SLOW TEMPO OF DENUDATION CLAIMED FOR EASTERN AUSTRALIA

SIR,—The average rate of lowering of the land surface by solution (chemical denudation) throughout the world is, according to data collected by Clarke (1924, p. 121) one foot in 30,000 years, or 2,000 feet in an interval extending back to the beginning of the Tertiary (60 million years). This takes no account of mechanical degradation, which cannot be negligible in a diversified landscape like that around Canberra, in eastern Australia. Noakes (1954, p. 128) confidently infers that at Canberra the erosional lowering (by chemical and mechanical denudation) during that time has been practically nil, though in valleys to the east it might amount to 100 feet.

Even though this applies to valley lowlands, and the hills bordering the lowlands have considerable relief, it may be taken to be applicable to the surface as a whole, if serious attention is to be paid to the claim (made by Noakes) that the general aspect of the landscape and particularly its relief have changed little since the Mesozoic (or even the Palaeozoic).

The hills immediately around Canberra have a relief of 800 to 1,000 feet,

with land slopes as steep as 20°, which may be estimated from published photographs; and relief in the surrounding country amounts to thousands of feet. Yet Noakes claims that " the lineaments [major landscape features] . . . seem to be legacies from the Palaeozoic ", with fault-line scarps that separate them becoming higher " as erosion progressed " since that time. In other words, a single erosion cycle has not only been in progress since Palaeozoic times, but has not yet passed beyond the stage of early maturity characterized by waxing relief. An argument that the land must have remained low-lying " to escape deep erosion " between the Triassic and the Tertiary, or that it has remained " at or near base level . . . since the Palaeozoic ", is of no significance in view of the existing strong relief, whether this be attributable to erosion during that interval or be assumed to have survived through it. It is not difficult to understand why the country has not been dissected to stronger relief, but the mystifying question is why strong relief which either was present initially or developed early in the cycle has not subsequently been destroyed by erosion which has been going on for 150 million years, whether the land remained low-lying or not.

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DETERMINATION OF [001] AXES IN MUSCOVITE

SIR,—I have read with great interest the paper " Regional Study of Epidote, Mica, and Albite Fabrics of the Moines " by C. B. Crampton, which appeared in your issue of March-April, 1957. It is particularly interesting because the author has determined the fabric of epidote and albite, minerals which are rarely dealt with in petrofabric analyses. The author has also made a large number of determinations of muscovite [001] Axes, another rather neglected problem in structural petrology. On this part of the paper I would like to make the following comments.

1. The author seems to have little confidence in a diagram of muscovite [001] Axes, published by me in 1945, because it was " measured from a section perpendicular to the foliation " and " it is impossible to differentiate between the Y and Z axes within sections perpendicular to the foliation ".

The impossibility of differentiating between the Y and Z axes in muscovite grains having the [001] cleavage planes perpendicular to the section is, I hope, a well known fact to all who have made such determinations. If, however, the angle between cleavage plane and thin section is about 70 degrees or less, the differentiation can easily be made, provided the optic angle is not abnormally low. After having placed the Y or Z axis parallel to A_4 (E-W horizontal axis) on the universal stage, the stage is rotated 45° about the A_5 (microscope axis), and the change in birefringence by rotation about A_4 is observed. If, for instance, 340 is read on the A_4 scale when the [001] plane is vertical, a rotation to 50 would bring one of the optic axes parallel to the tube of the microscope, if Y is parallel to A_4. If Z is parallel to A_4, the same rotation would bring parallel to the tube a direction in the XY plane which is 30 degrees from X. If by rotation on A_4 the X direction can be brought parallel to the tube, a very low birefringence is usually observed. Besides the angle between the observed direction and the [001]

cleavage the gypsum plate can in most of these cases be used to determine whether X or an optic axis is parallel to the tube.

The diagram referred to by Crampton was made from a section normal to the megascopic foliation, but as the maximum of [001] poles made an angle of 30 degrees with the normal to the foliation, a large majority of the grains had an orientation which permitted a reliable identification of Y. Only such grains where this could be done were included in the diagram. For further control some measurements were made in the section parallel to the megascopic foliation, which, however, contained fewer grains than the section used for the diagram.

These details were not included in my paper, as the position of the maximum of [001] poles was given in the text and could be clearly seen in the diagram. This omission has apparently given rise to doubt as to the accuracy of the diagram.

Recently I checked my old slides and arrived at the same result as in 1945. I can therefore assert that my diagram was correct.

2. The method of measuring the azimuth of Z′ as a substitute for the more time-consuming procedure of determining the Y axis, a method that was introduced by Sander, and has been used among others by Crampton, has, unfortunately, great disadvantages, and unless it is used with great caution may easily lead to erroneous results. The method is based on the assumption that Z′ is perpendicular to the Y axis. In muscovite with $2V = 35–40°$ this assumption is valid only when the angle between [001] of the grain and the thin section is less than about 10°. With greater angles between [001] and the thin section the angle Z′ to Y may vary considerably. In the interval 20° to 30° the angle Z′ to Y may change from 90° to 0°, with a change of only a few degrees in the position of the X axis.

Rocks where the great majority of muscovite [001] planes make angles of less than about 10° with the foliation are extreme s-tectonites, which are not common in metamorphic rocks. In order to obtain reliable results with the Z′ method, one must restrict the measurements to the grains having [001] very nearly parallel to the slide. This procedure involves the difficult task of deciding which grains are sufficiently parallel to the slide to justify a measurement. Further, it leaves the orientation of Y in the other grains, which usually constitute the majority, entirely unknown.

If the measurements are not restricted to the grains having [001] very nearly parallel to the slide, the rapid change in the angle Z′ to Y for grains having [001] at 20°–30° to the slide may in the diagram indicate a spreading in the orientation of Y where there is none. If several grains with larger angles between [001] and the slide are measured, the diagram may give the impression of a definite concentration of Y axes in the tectonic *ac* plane in cases where this concentration by an accurate determination of the Y axes is found to be very problematic.

That these objections to the method are serious, can be seen by measuring Z′ and determining the XYZ axes in a sufficiently large number of muscovite grains in a slide and plotting them in a diagram.

I have recently made some such diagrams. The study is not completed, but the results so far have convinced me that if one wants to obtain reliable information about the orientation of [001] in muscovite, there is no substitute for the time-consuming method of determining the Y axis on the universal stage. The importance commonly attached to these diagrams is so great that the extra amount of time spent is justified. In the discussion of problems of great importance to the understanding of the tectonic history of an area, it is better to have a few diagrams which are known to be correct than to have many diagrams which may possibly be correct, but which may also be so inaccurate as to give a rather different picture from that which the accurate diagrams would have given.

I therefore have arrived at the conclusion that the Z′ method of determining the orientation of the [001] axes of muscovite should preferably be discarded altogether.

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